Patterns and Factors Involved in Fractures and Dislocations to the KNEE-THIGH-HIP COMPLEX in Frontal Crashes

A preliminary analysis of the U of M CIREN Database

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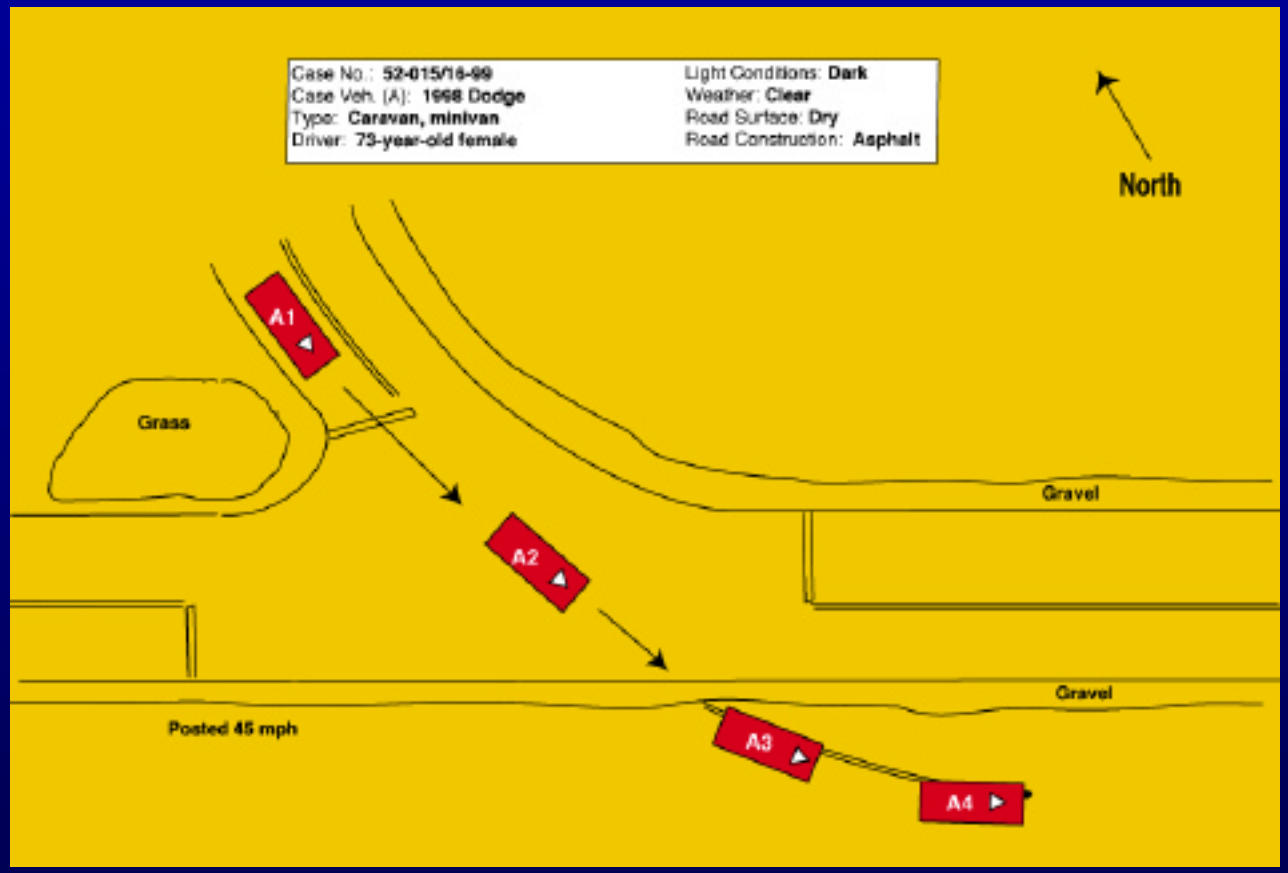
May 5, 2000
The NHTSA
Washington, D.C.

Example Case

resulting in left acetabular fracture and right femur fracture to unbelted right-front passenger in a left-sided, 24-mph offset-frontal collision with a tree

Crash Scenario



- 1998 Dodge Caravan
- Went off the road and struck a 28-cm diameter tree with the left front in an offset mode
- CDC = 12-FLEN-4
- Delta V est. at 24 mph
- 32 cm of direct damage
- 56 cm maximum crush

Crash Scene

path of case vehicle

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Crash Scene

path of case vehicle

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Crash Scene

path of case vehicle

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Crash Scene

struck object - 28-cm diameter tree

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Crash Scene

looking back on path of case vehicle

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Case Vehicle - 1998 Dodge Caravan

exterior damage

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Case Vehicle - 1998 Dodge Caravan

exterior damage

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Case Vehicle - 1998 Dodge Caravan

exterior damage

U of M CIREN

Case Vehicle - 1998 Dodge Caravan

exterior damage

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Case Vehicle - 1998 Dodge Caravan

exterior damage

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Case Vehicle - 1998 Dodge Caravan

interior damage

Case Vehicle - 1998 Dodge Caravan

interior damage

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Case Vehicle - 1998 Dodge Caravan

interior damage - steering wheel rim

Case Vehicle - 1998 Dodge Caravan

interior damage - driver airbag and toepan area

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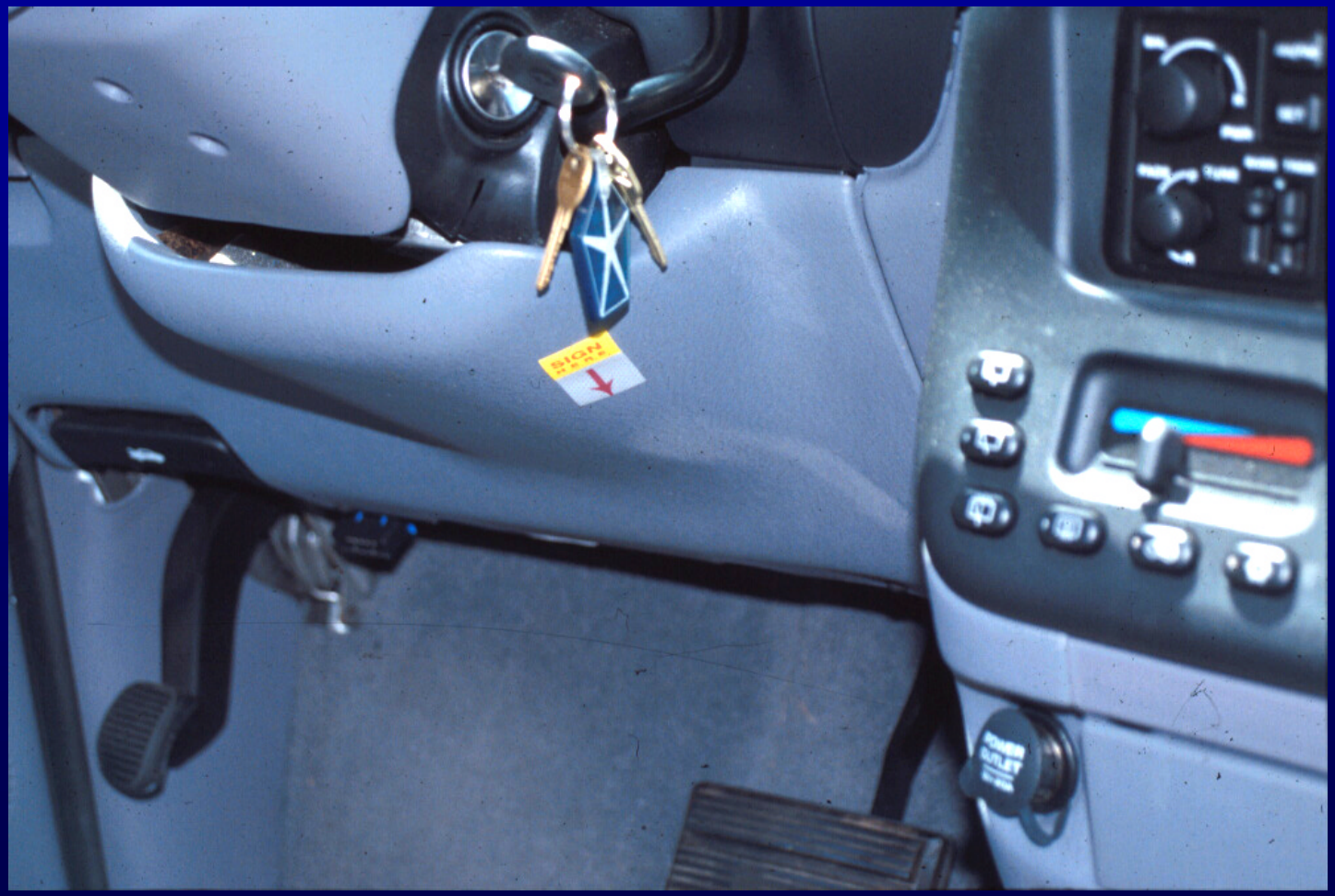
Case Vehicle - 1998 Dodge Caravan

interior damage - driver knee bolster area



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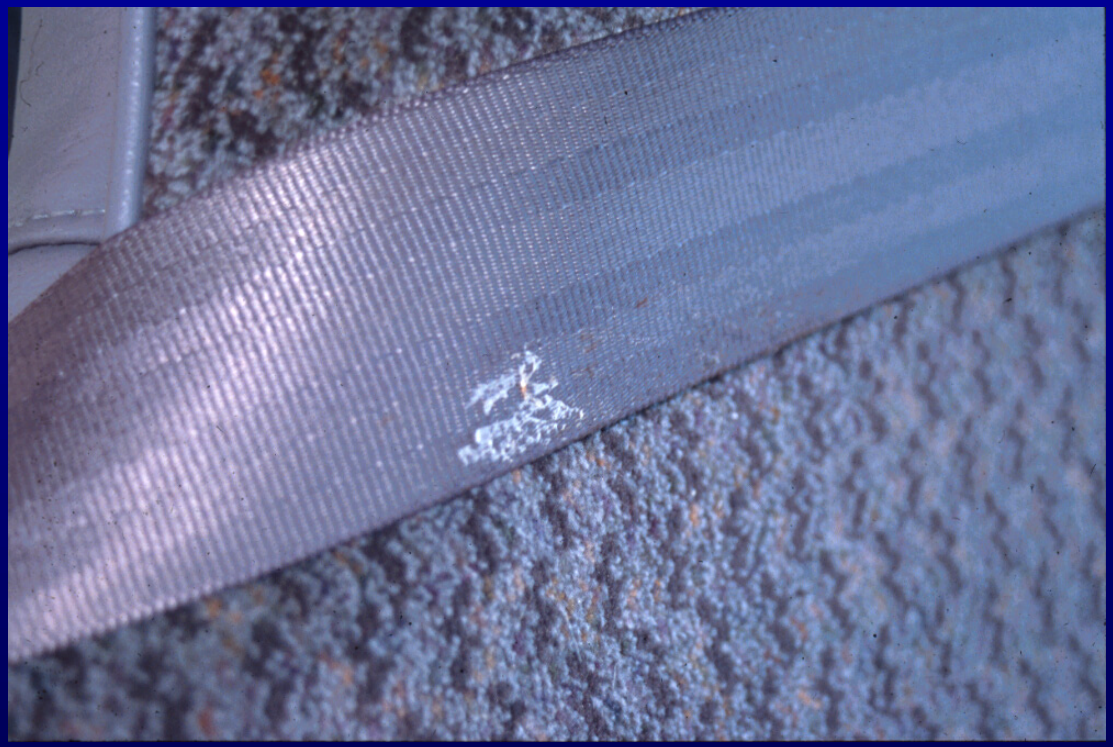
Case Vehicle - 1998 Dodge Caravan

Driver-side D-ring showing webbing imprint

Case Vehicle - 1998 Dodge Caravan

Driver's shoulder belt



Case Vehicle - 1998 Dodge Caravan

interior toward passenger side

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Case Vehicle - 1998 Dodge Caravan

Right-front passenger D-ring showing no imprint

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Case Vehicle - 1998 Dodge Caravan

right-front passenger airbag

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Case Vehicle - 1998 Dodge Caravan

right-front passenger knee bolster area

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Case Vehicle - 1998 Dodge Caravan

contact mark from RF passenger's left knee

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Case Occupant
Right-Front Passenger

- 79-year-old male
- 6 ft, 0 in tall
- 175 lb
- three-point belt not worn
- frontal-impact airbag deployed

ER Evaluation

- Alert & oriented.
- Complained of right knee and left hip pain.
- BP 140/85, P 90, RR 20 (90% sat - 4L NC)
- Exam:
  - Chin laceration
  - Abrasions and contusions to chest and abdomen
  - Swelling of L forearm and hand
  - Bilateral knee contusion. Deformity on R.

Summary of Injuries

- AIS-4
  - Right frontal subdural hematoma, small
- AIS-3
  - Right femur supracondylar fracture
  - Left acetabular fracture (roof and posterior column)
- AIS-2
  - Metacarpal fractures
- AIS-1
  - Multiple contusions and lacerations

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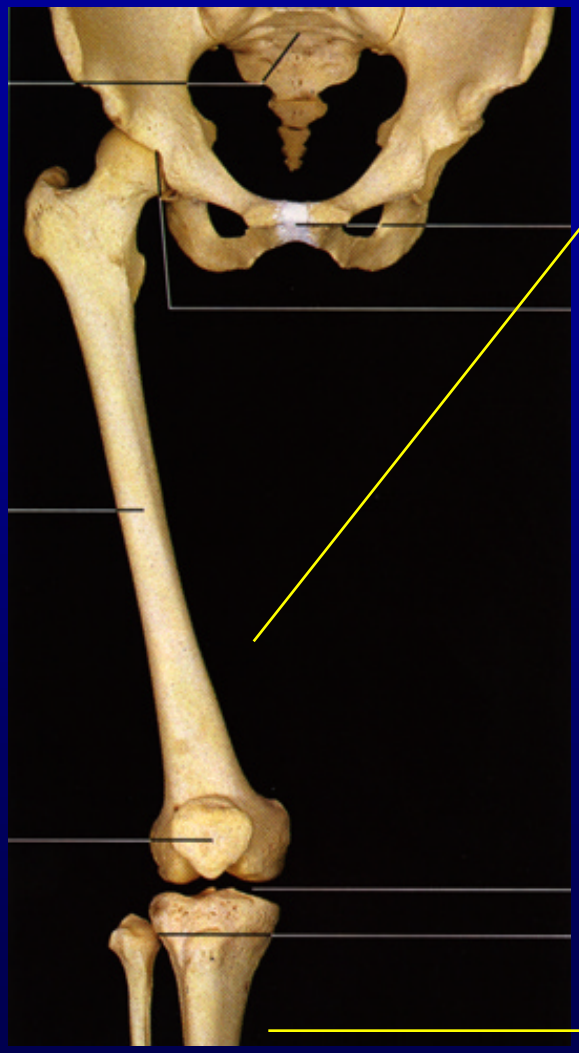

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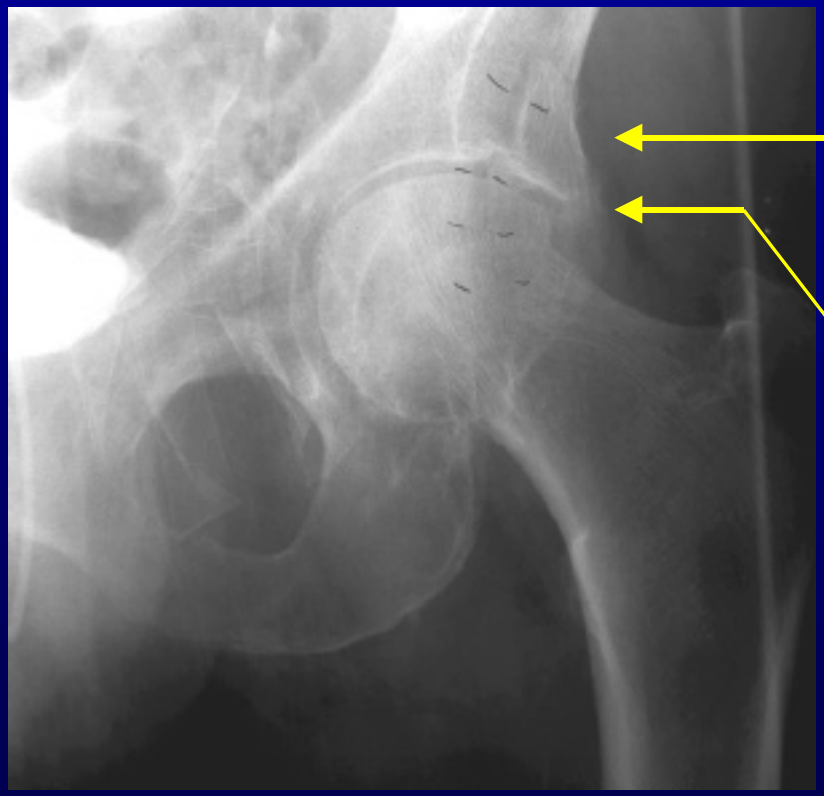
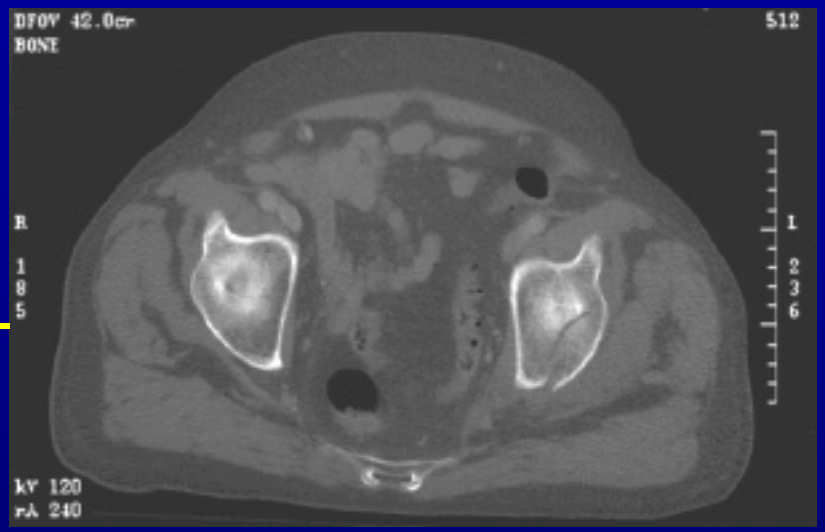
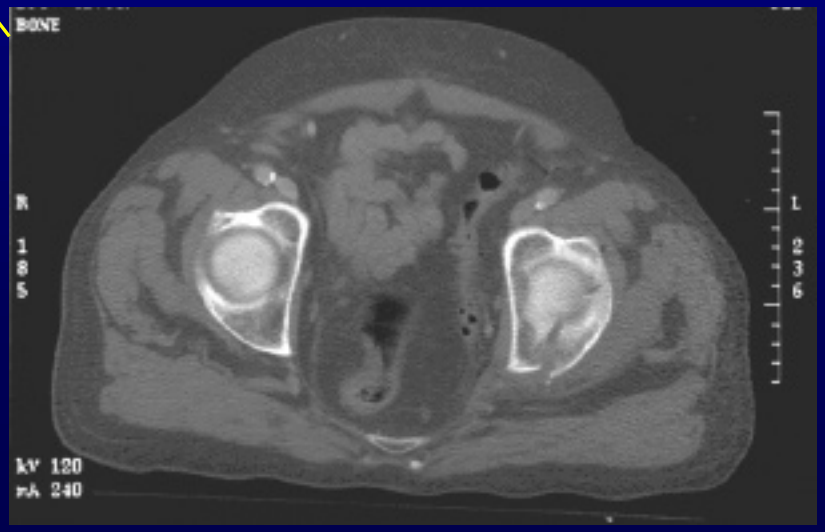



DFOV 42.0cm
BONE
512
R
1
8
5
1
2
3
6
kV 120
mA 240


BONE
R
1
8
5
1
2
3
6
kV 120
mA 240

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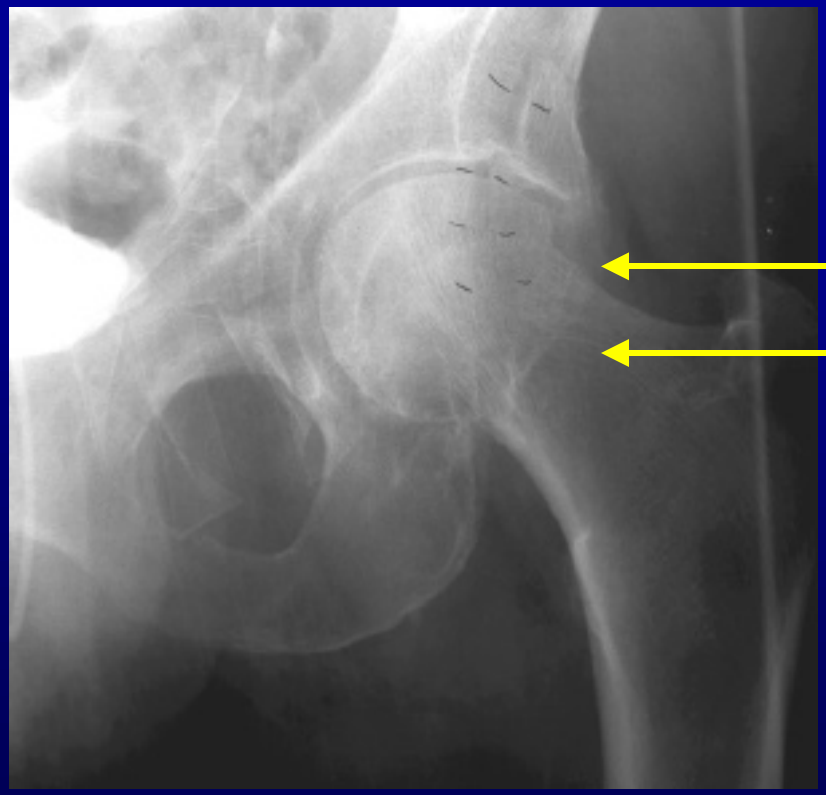

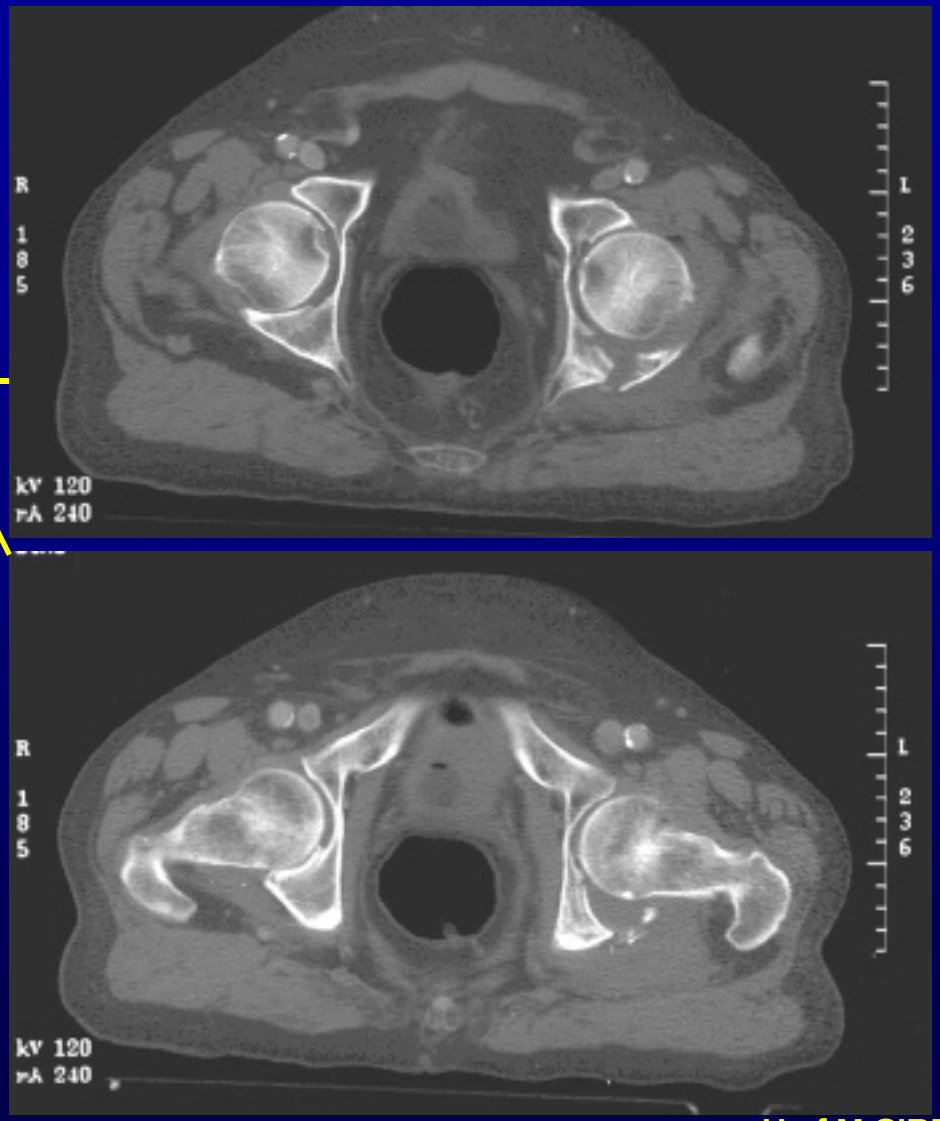

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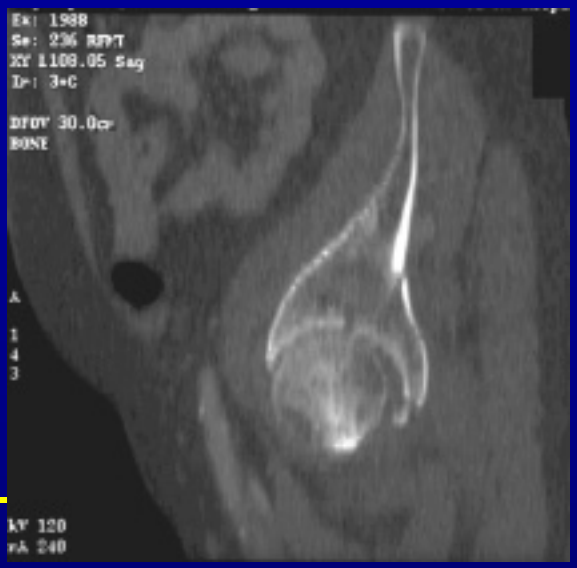
Ex: 1988
Se: 236 RFVT
XY 193.29 Sag
Ir: 2+C
DFOV 30.0cm
BONE
A
1
4
3
kV 120
mA 240
Large


Ex: 1988
Se: 236 RFVT
XY 1108.05 Sag
Ir: 3+C
DFOV 30.0cm
BONE
A
1
4
3
kV 120
mA 240

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Treatment Course

- **Post Injury Day #2:**
  - **Operative repair of**
    - **Right femur supracondylar fracture**
    - **Left acetabular fracture (roof and posterior column)**

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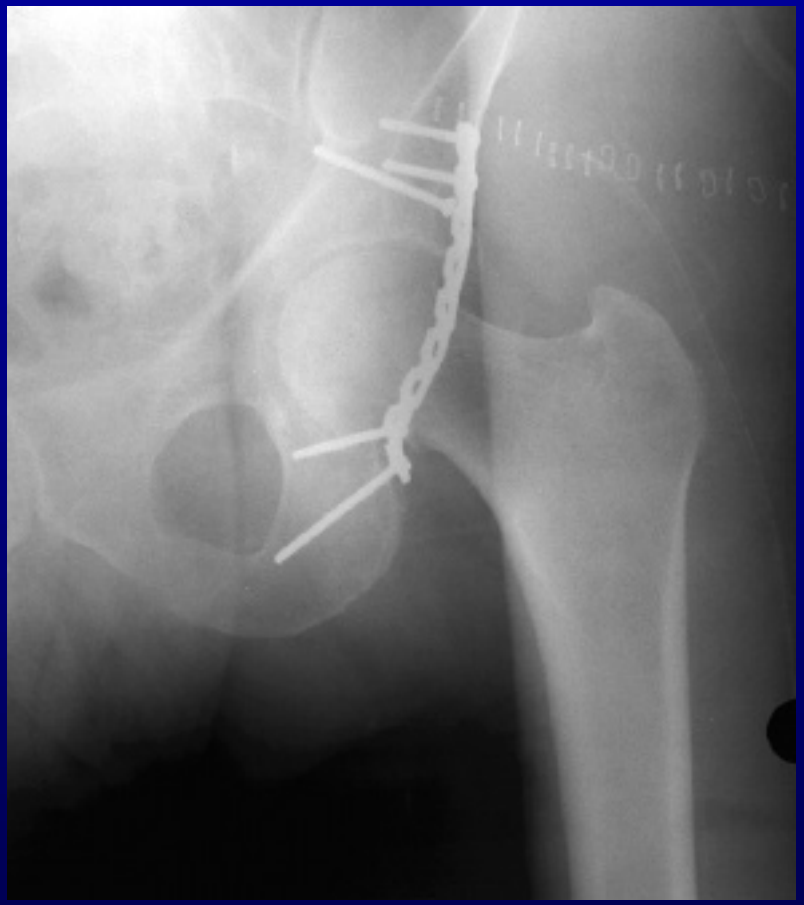

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Treatment Course

- **Post Injury Days 3 - 8**
  - **Renal dysfunction - oliguria**
  - **Cardiac dysfunction - arrhythmias, ischemia**
  - **Pulmonary dysfunction - ventilator dependent**

Treatment Course

- **Post Injury Day #8:**
  - **Neurologic deterioration.**
  - **CT Head:**
    - **R frontal subdural hematoma.**

AIS-4

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Treatment Course

- **Post Injury Days 9-16**
  - **Worsening multi-organ failure.**
- **Post Injury Day 17**
  - **Care withdrawal. Patient expires.**

Observations

- Elderly occupants are vulnerable to injury.
- Pre-existing conditions greatly affect outcome.
- Immobility secondary to his lower extremity injuries contributed to his poor medical outcome.

- **Had he survived, he was at high risk for poor functional outcome with injuries to both of his main weight-bearing extremities.**

Knee/Femur/Hip Injuries Rated by Severity of Disability

Hip
- Hip fracture/dislocation involving articular cartilage
- Femoral head fracture
- Femoral neck fracture

Knee
- Supracondylar fracture

Thigh
- Subtrochanteric fracture
- Shaft fracture

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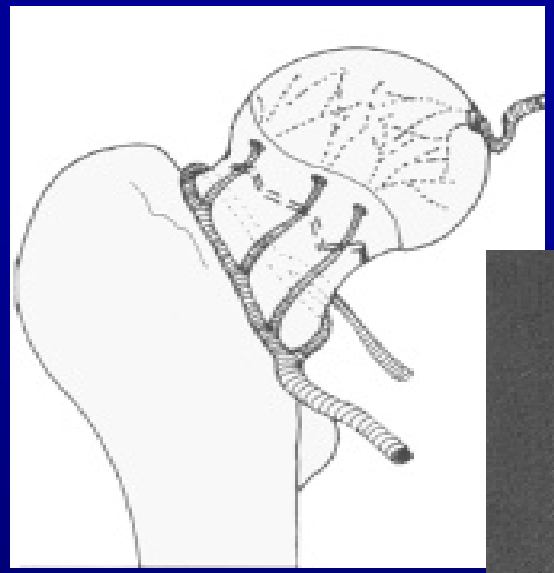
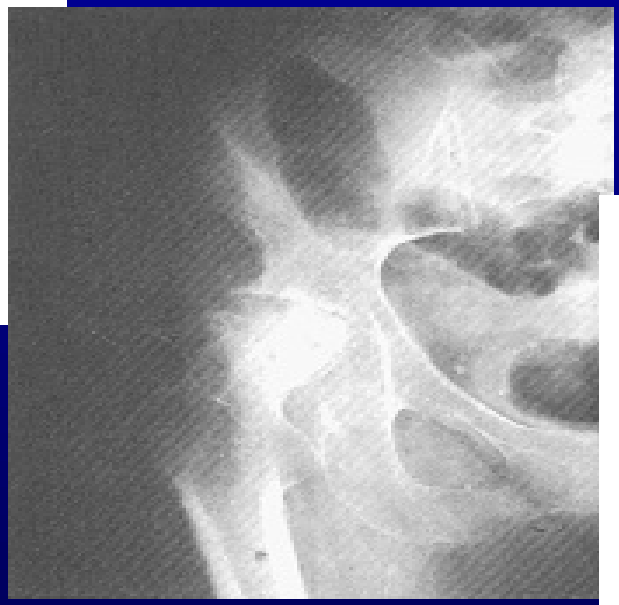
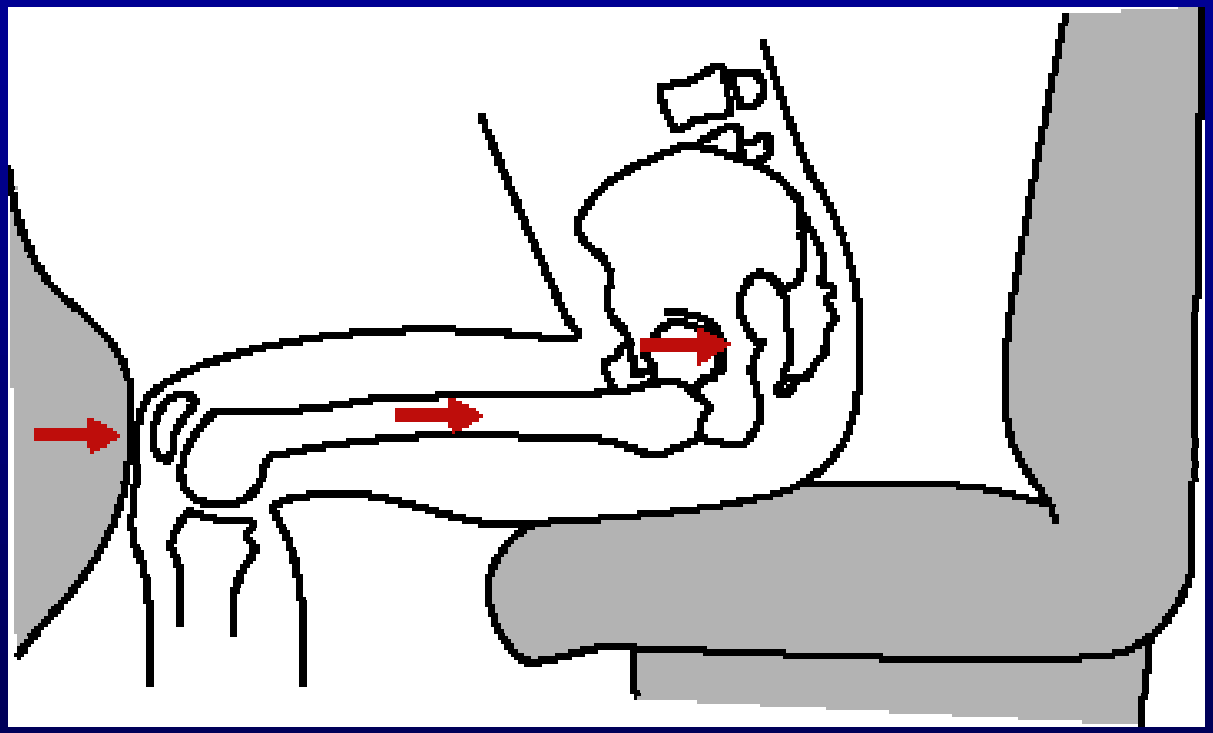


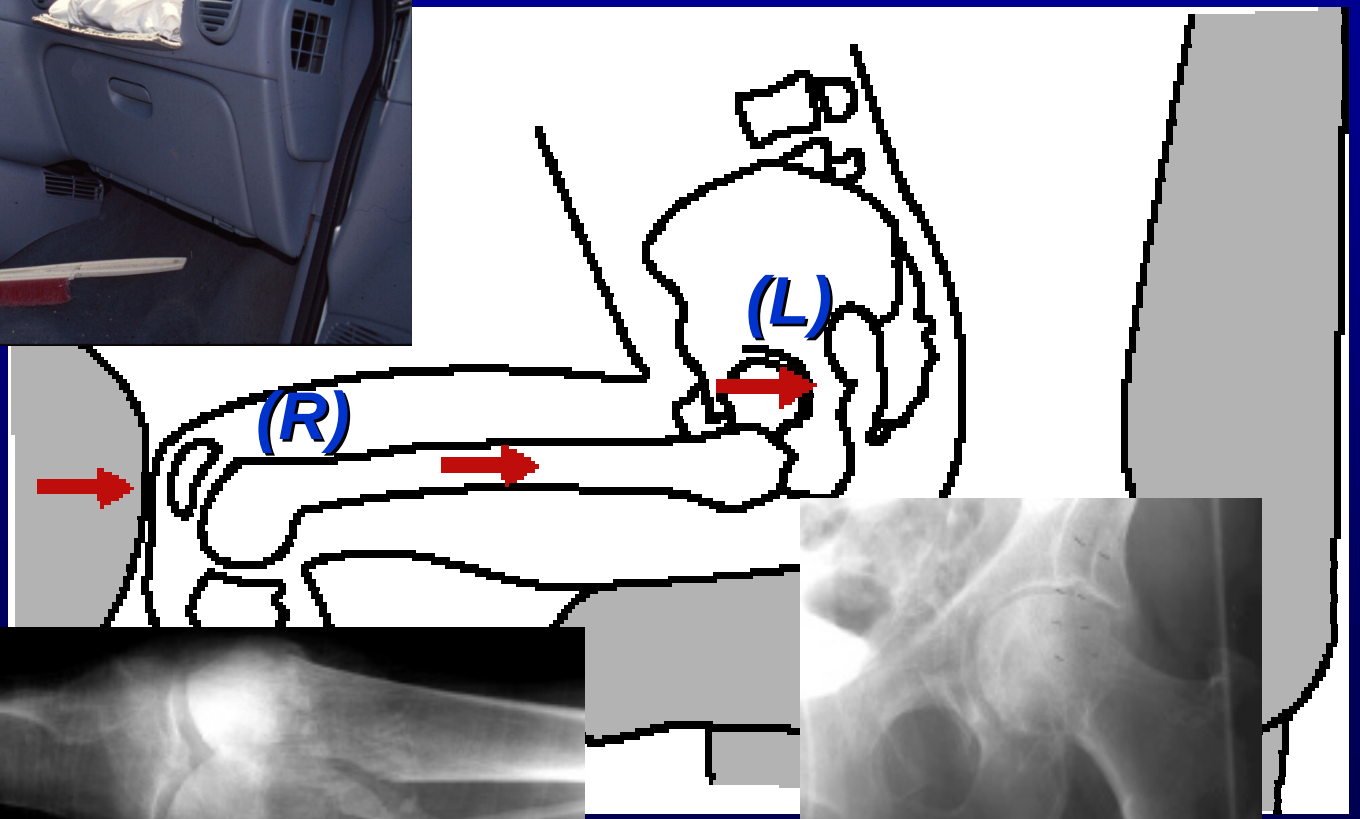


Injury Mechanisms

INJURY	CONTACT	MECHANISM
R Frontal Subdural	Hand/Airbag Fling	Acceleration
R Femur	Knee Bolster	Compression (Axis)
L Acetabulum	Knee Bolster	Compression (through femur axis)



Similar contact and loading… Different injuries. Why?



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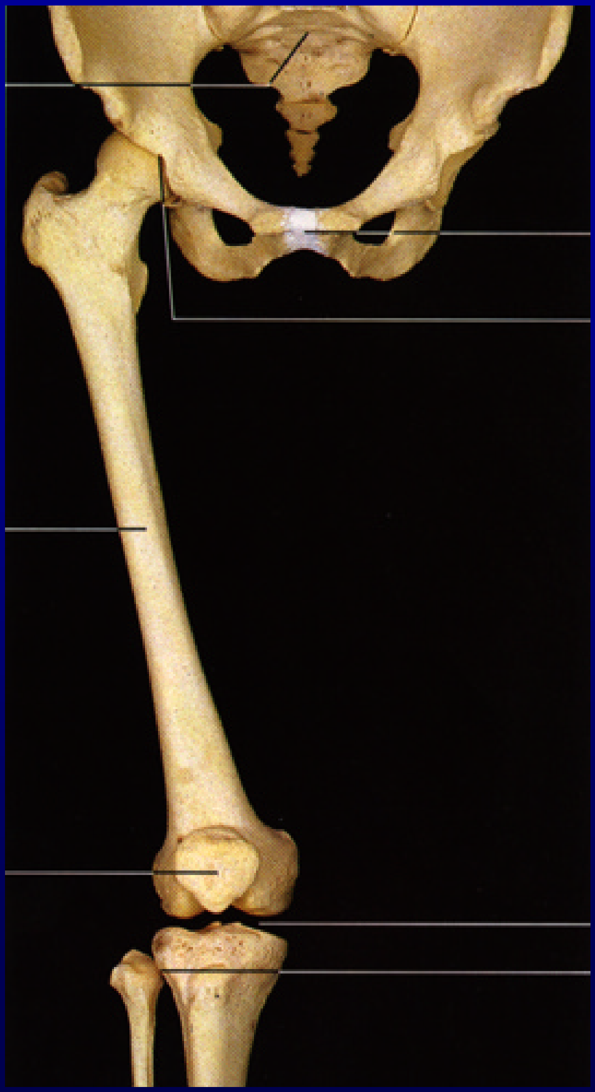
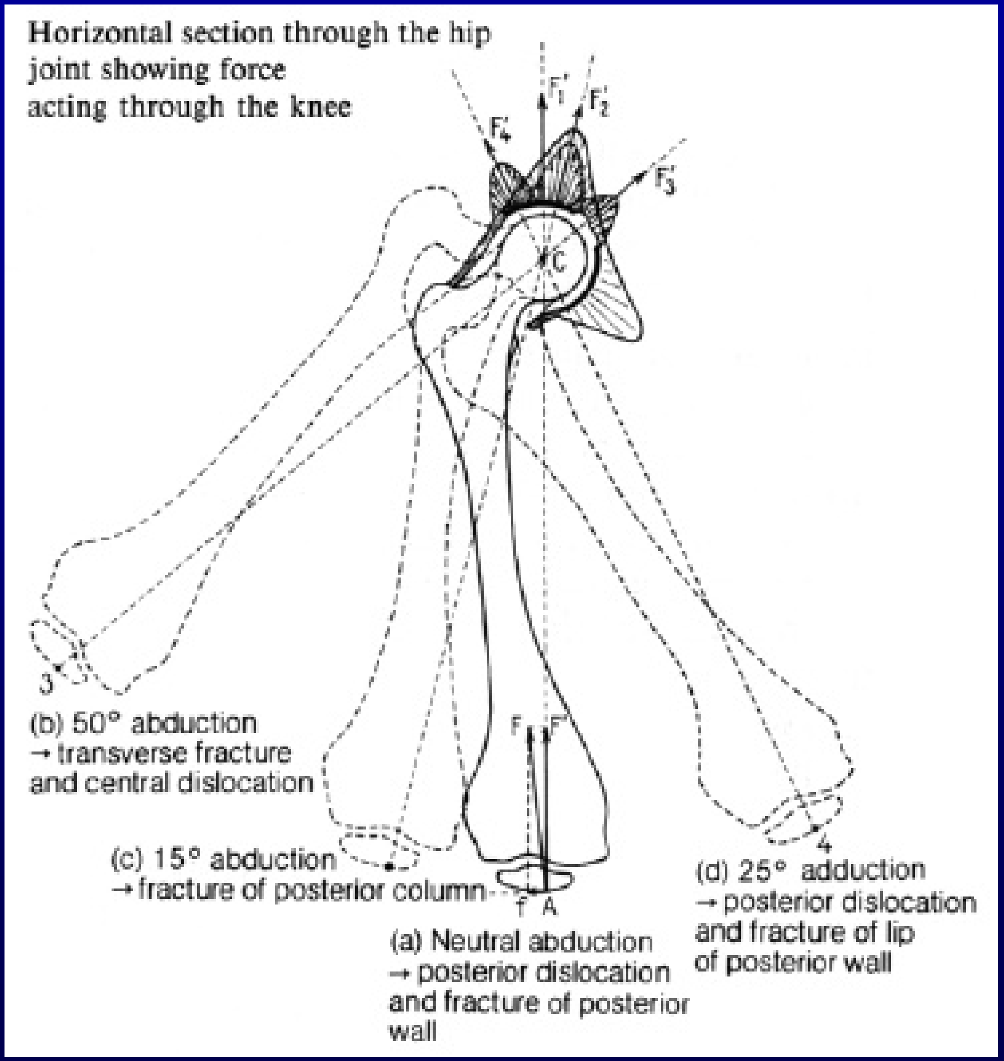
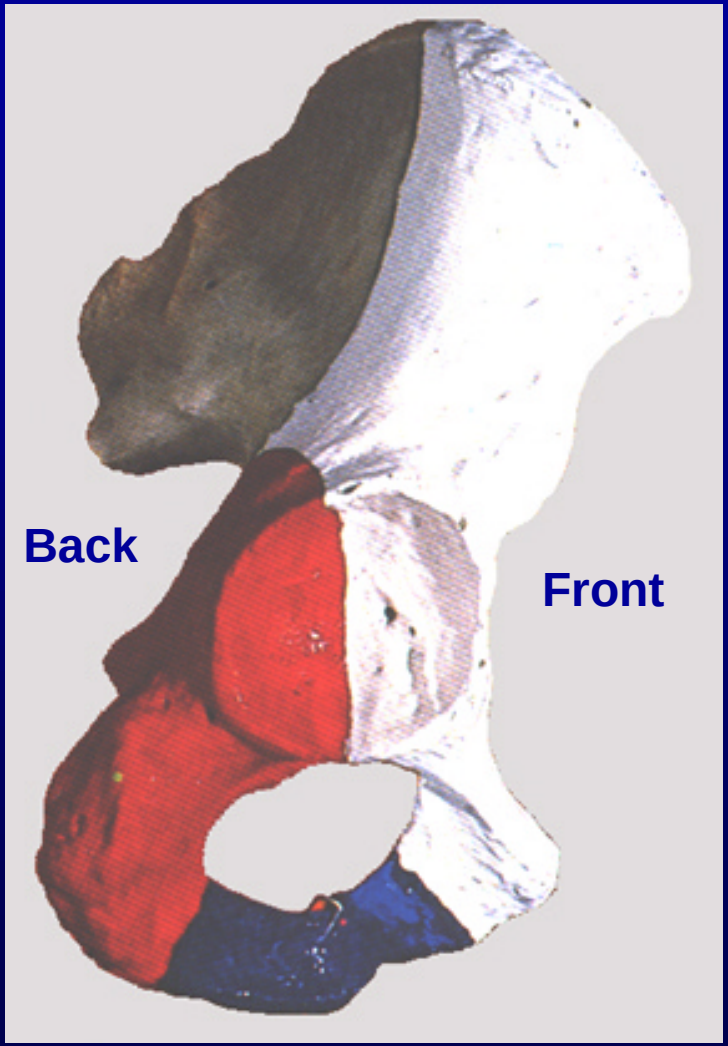
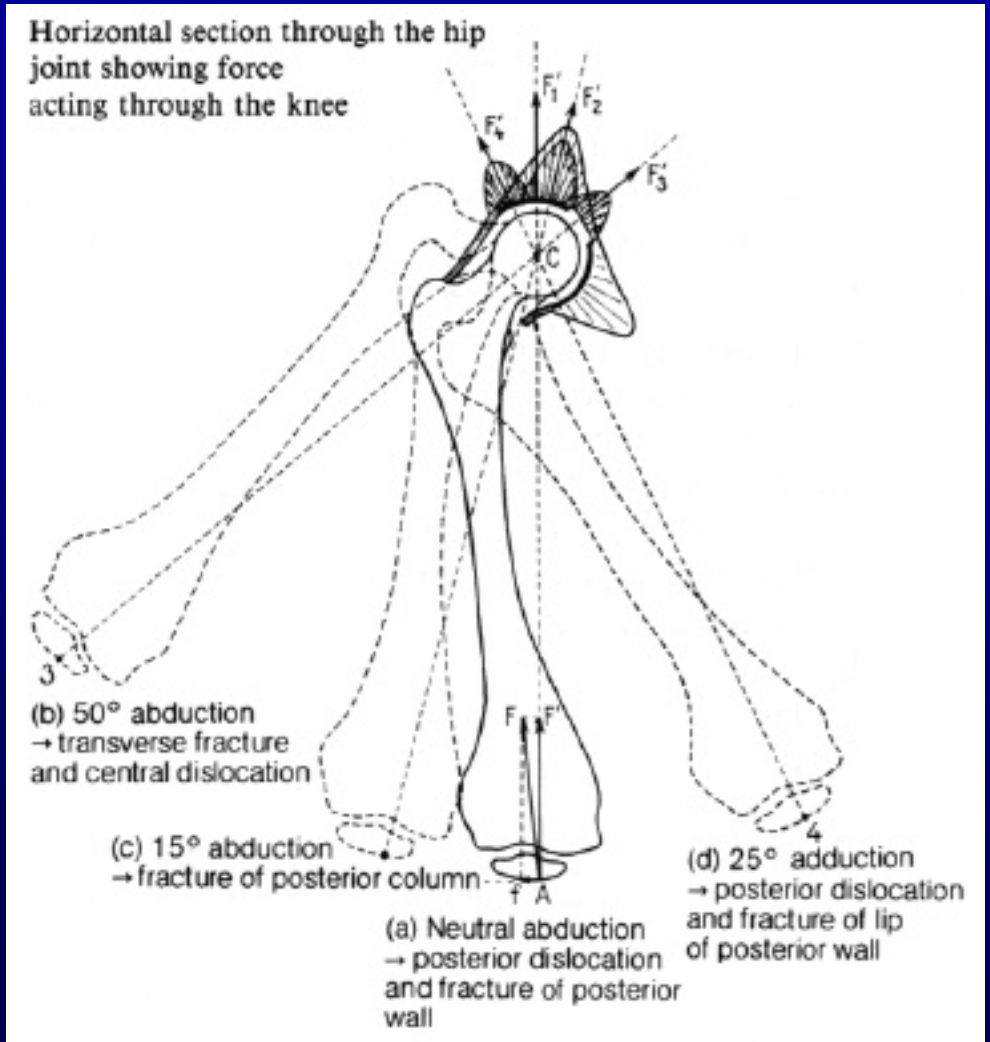


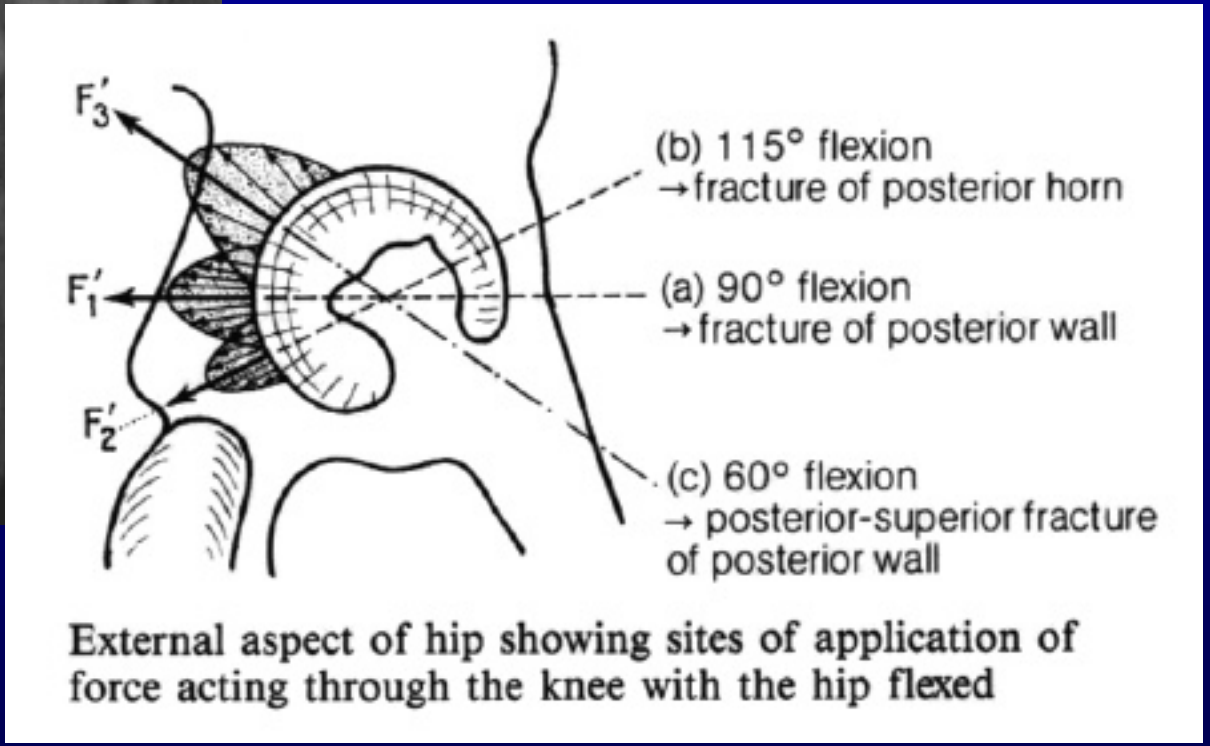

Horizontal section through the hip joint showing force acting through the knee
F'1
F'2
F'3
F'4
C
3
4
F
F'
f
A
(b) 50° abduction → transverse fracture and central dislocation
(c) 15° abduction → fracture of posterior column
(a) Neutral abduction → posterior dislocation and fracture of posterior wall
(d) 25° adduction → posterior dislocation and fracture of lip of posterior wall

Letournel


Back
Front


Horizontal section through the hip joint showing force acting through the knee
F'1
F'2
F'4
F'3
C
3
(b) 50° abduction
→ transverse fracture
and central dislocation
F
F'
(c) 15° abduction
→ fracture of posterior column
f
A
(a) Neutral abduction
→ posterior dislocation
and fracture of posterior
wall
4
(d) 25° adduction
→ posterior dislocation
and fracture of lip
of posterior wall

Letournel



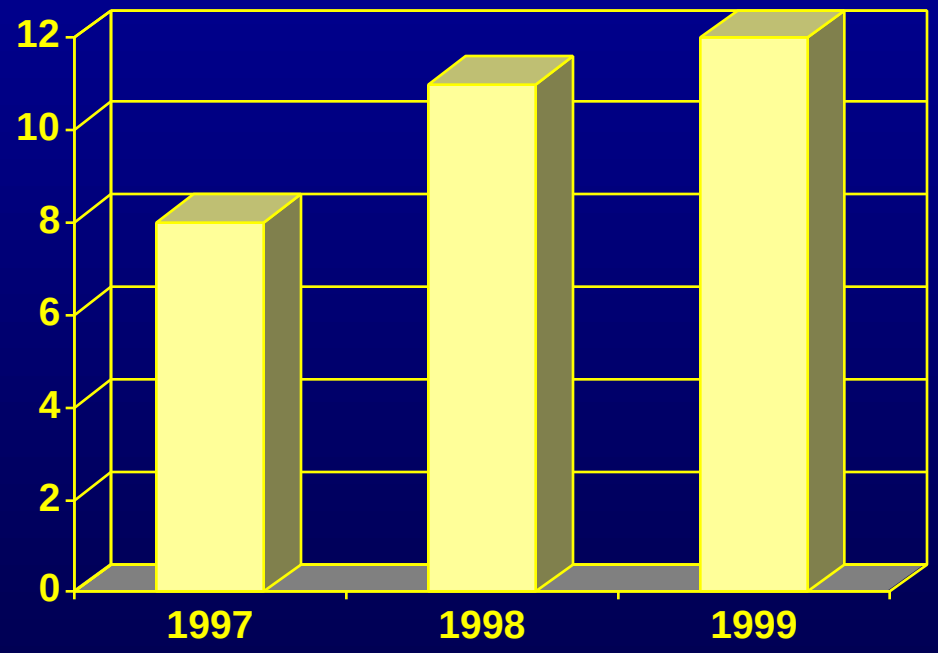
External aspect of hip showing sites of application of force acting through the knee with the hip flexed

Letournel

Post-op

- Don’t bend hip more than 70 degrees, i.e. Don’t lean forward while sitting.
- Don’t turn or roll leg inward.
- Keep knees apart

Hip Joint Injuries in Frontal Crashes
Michigan CIREN



K-T-H Fractures/Dislocations in UM CIREN
U of M CIREN Database Analysis

Patterns of Injuries versus
Crash, Vehicle, and Occupant Factors

Independent Variables

- Crash Severity
- Location of Front-End Damage (CDC)
- % Vehicle Overlap
- Rearward Knee bolster Intrusion
- Vehicle Model Year
- Restraint Usage (lap belt)
- Occupant Kinematics
- Occupant Age
- Occupant Location (DR vs. RF)
- Occupant Gender

Dependent Variables

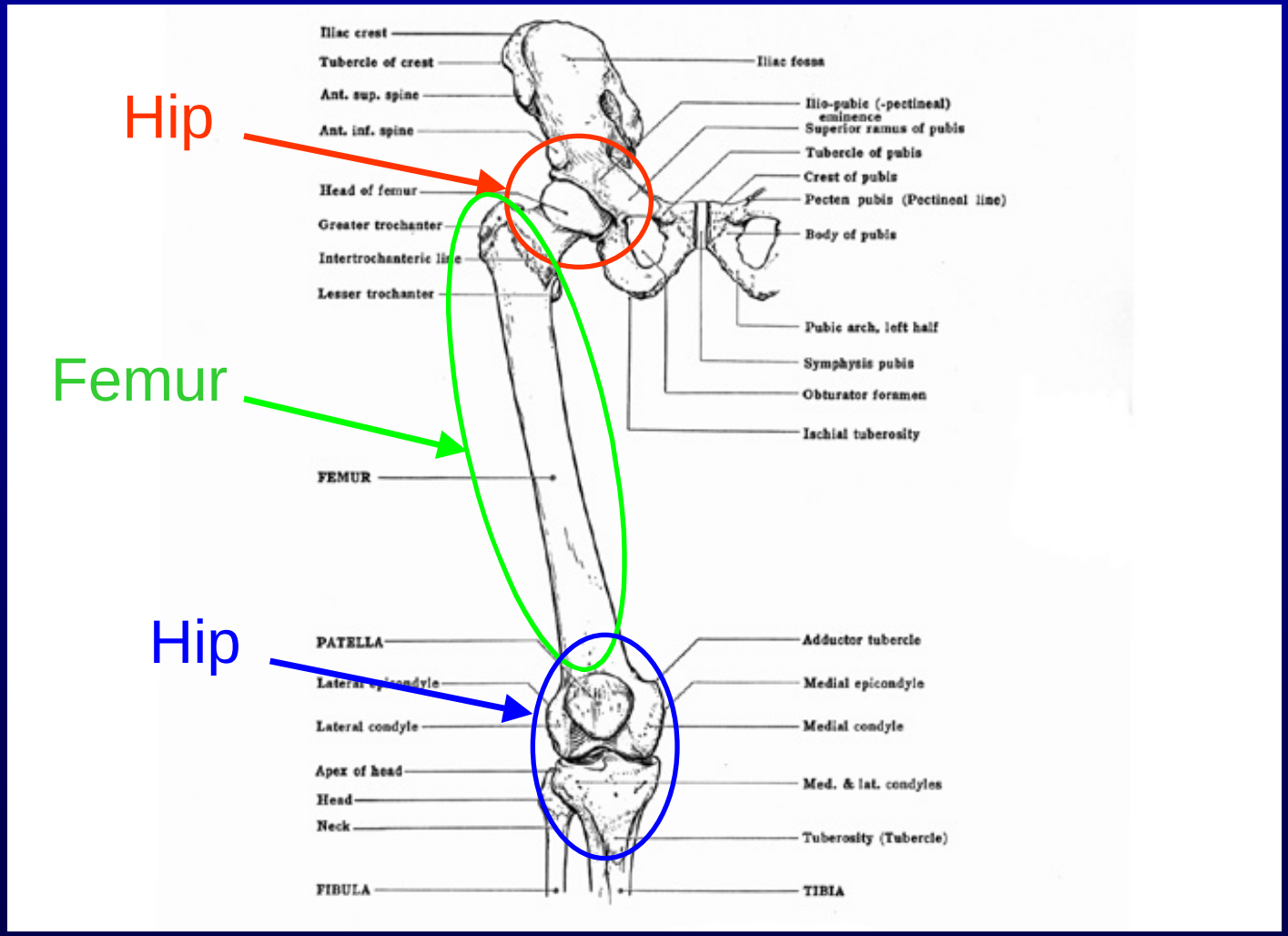
- Hip Fractures/Dislocations
- Femur Fractures
- Knee Fractures
- Side of body injured

Fractures and Dislocations of the Knee-Thigh-Hip Complex in Frontal Crashes

U of M CIREN Database

- as of 8/31/99
  - 49 case occupants with KTH fractures/dislocations
- as of 5/5/00
  - 57 case occupants with KTH fractures/dislocations

Fractures and Dislocations of the Knee-Thigh-Hip Complex in Frontal Crashes



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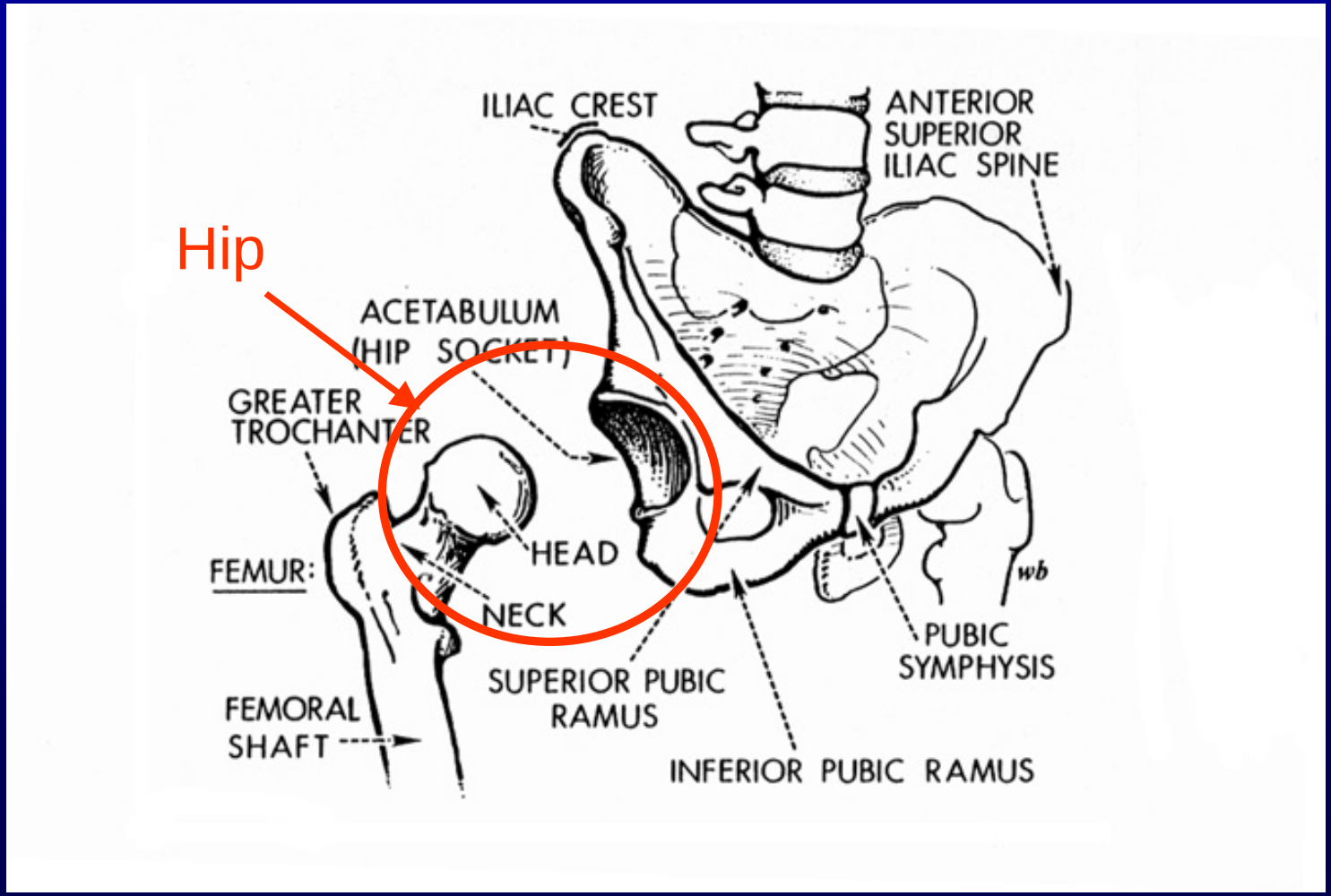
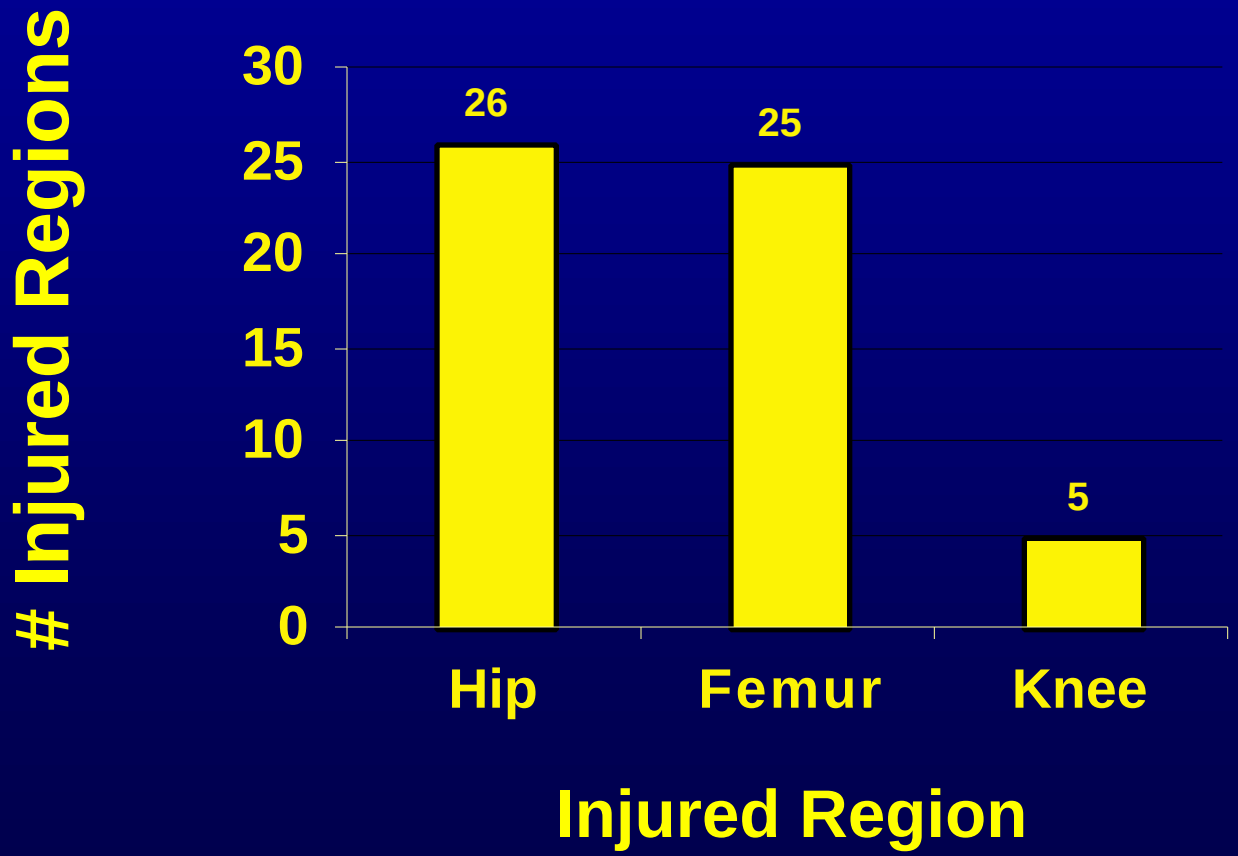
Fractures and Dislocations of the Hip



K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Injured Body Regions (N = 56)



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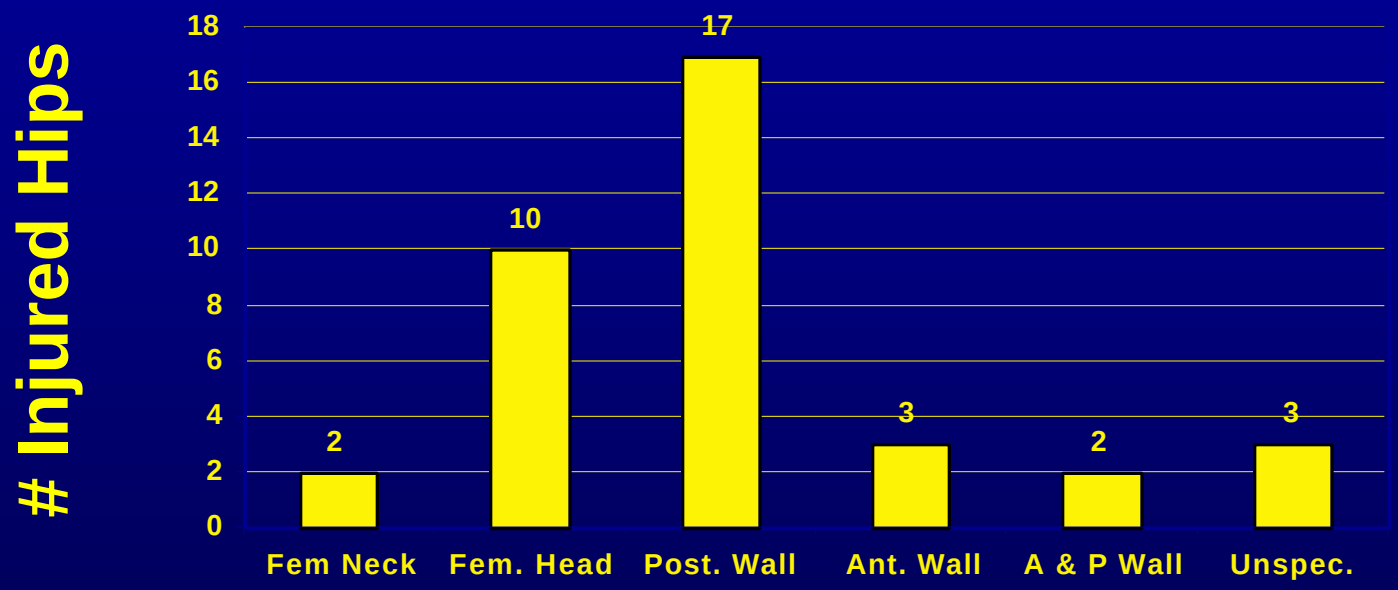
Hip Fractures/Dislocations in UM CIREN Frontal Impacts as of 5/5/00

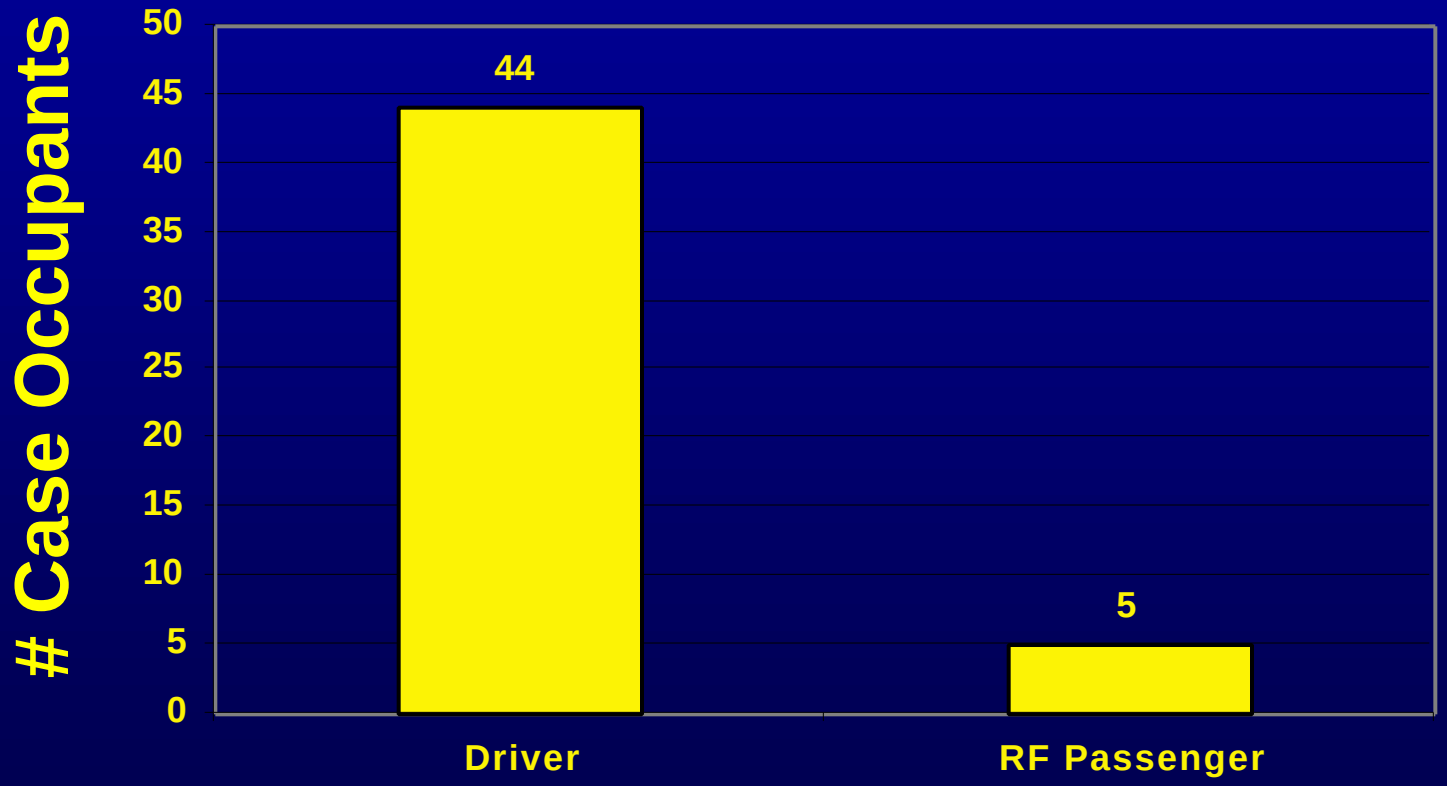
Distribution of Hip Fractures



Location of Hip Fracture/Dislocation

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Injured Occupant Location



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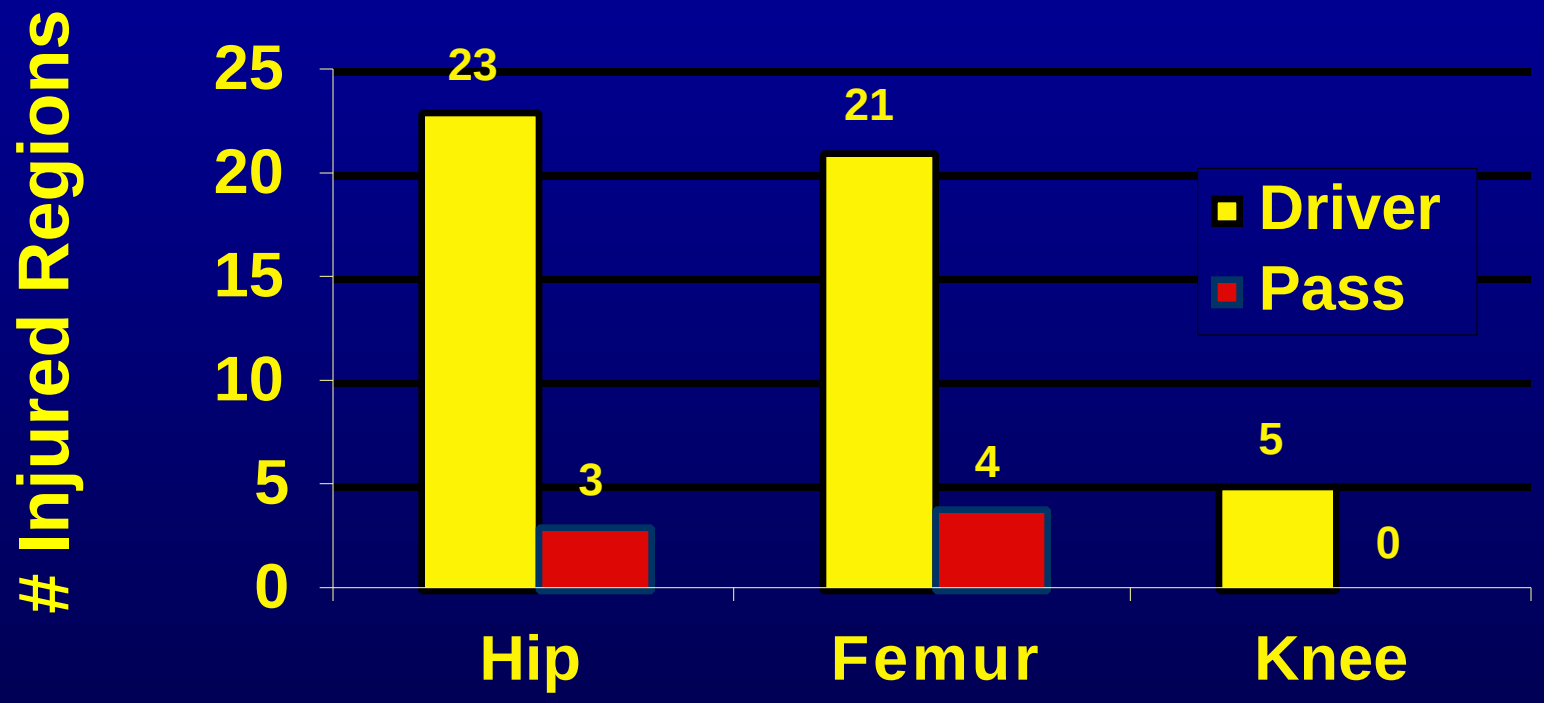
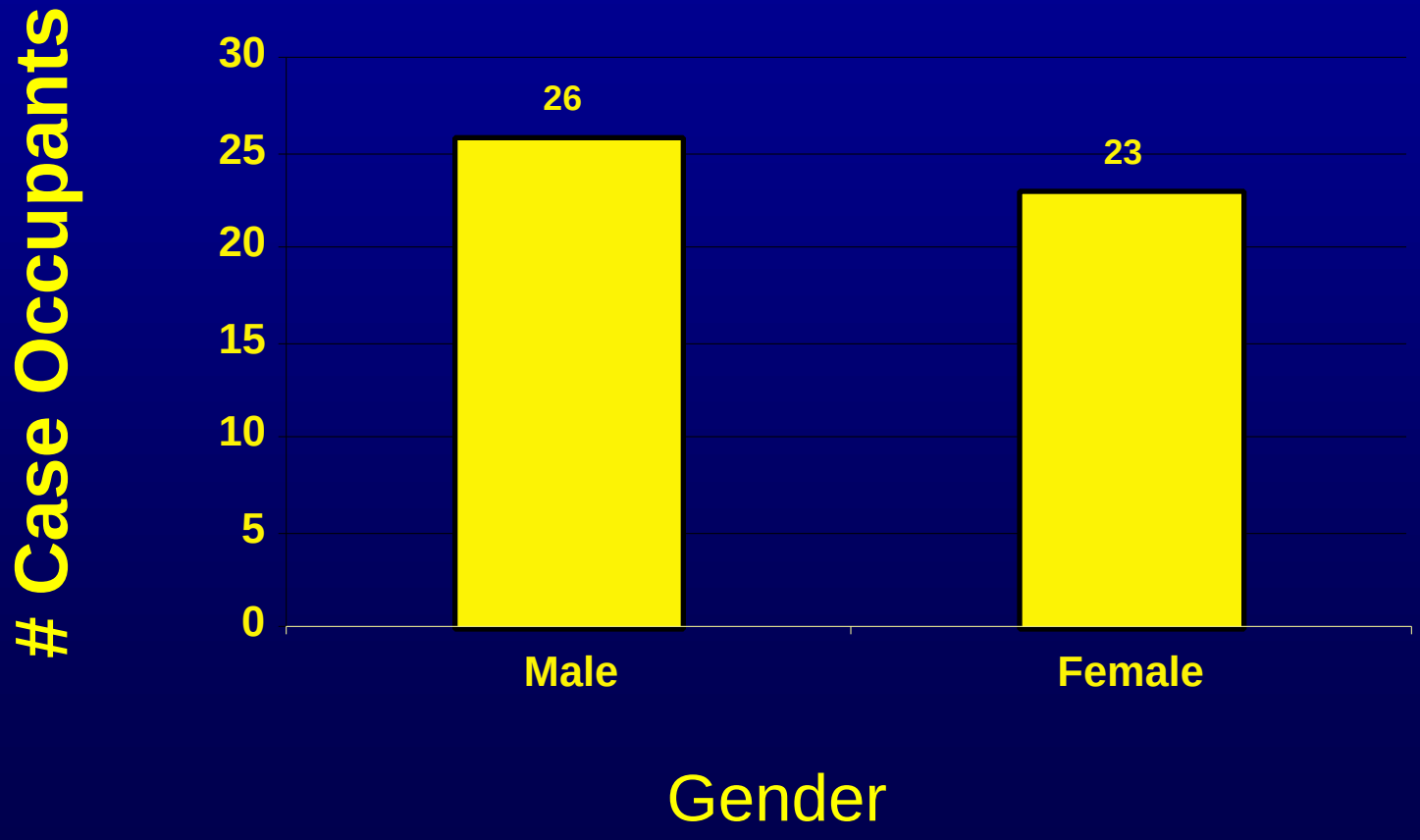
K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Occupant Location by Injured Region



K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Injured Occupant Gender



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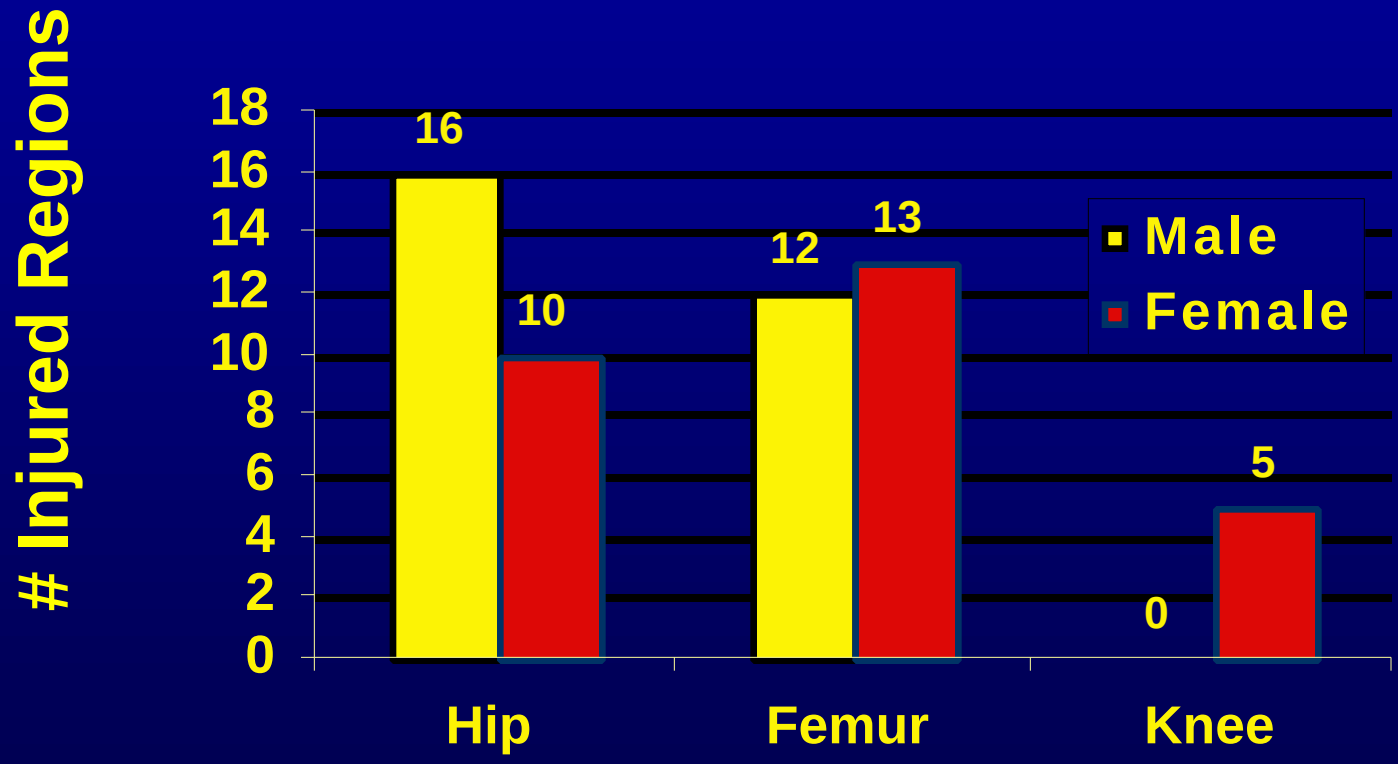
K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Occupant Gender by Injured Region



Gender by Injured Region

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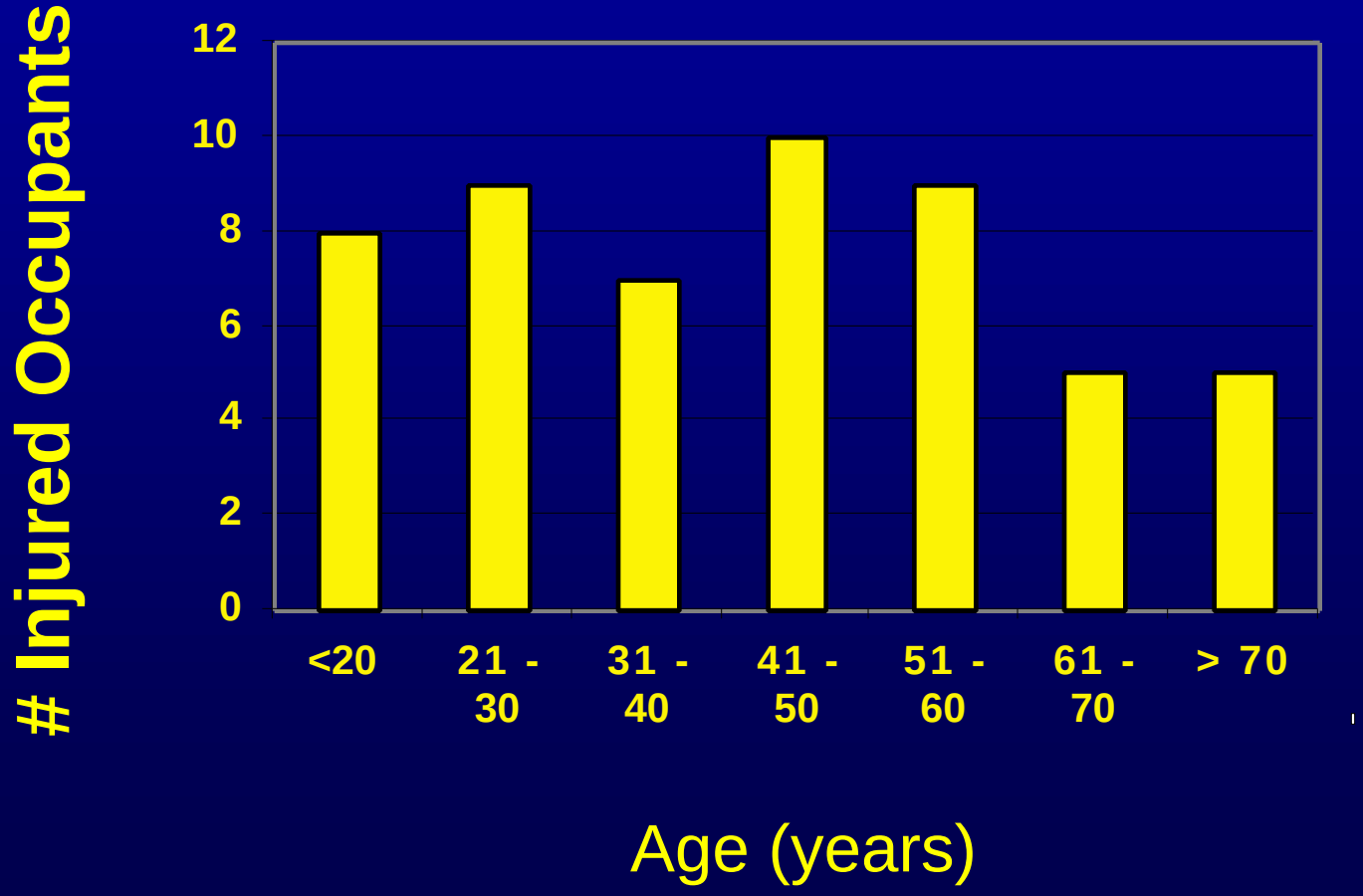
K-T-H Fractures/Dislocations in UM CIREN as of 5/5/00

Distribution of Injured Occupant Age



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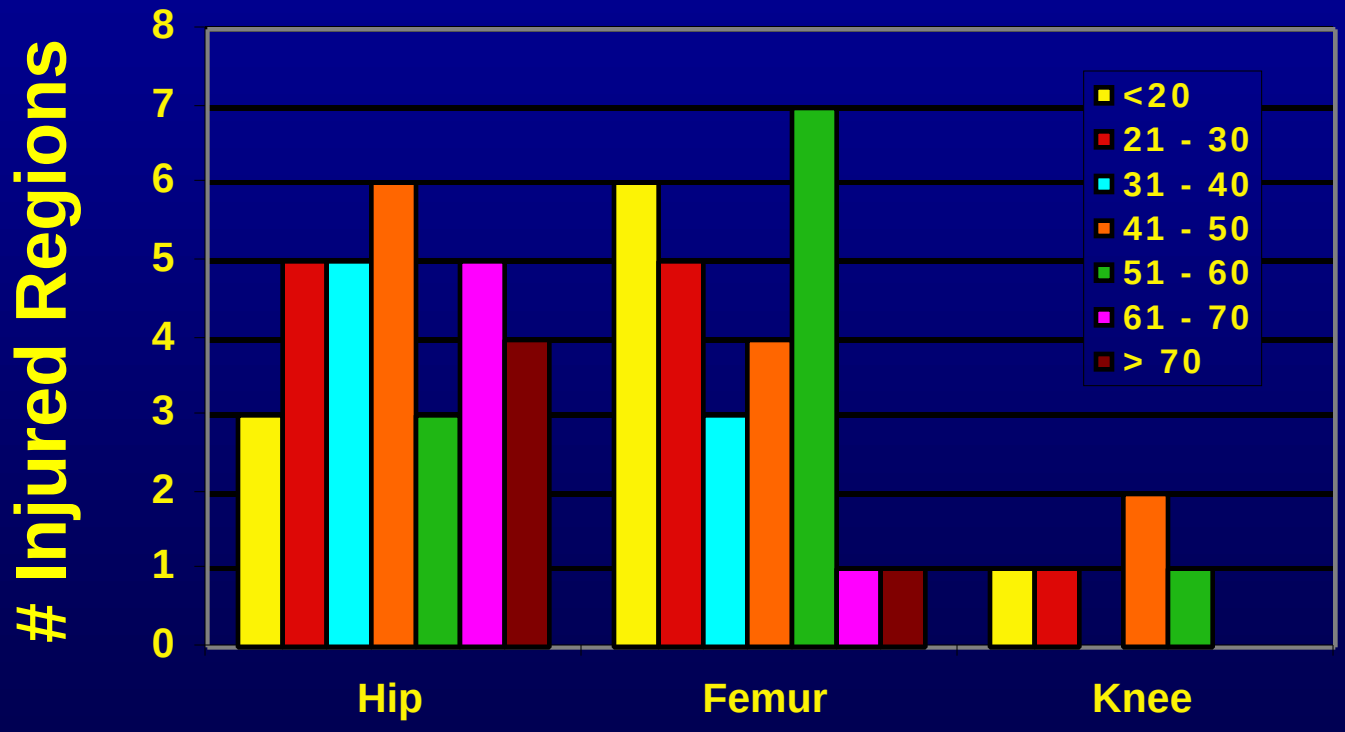
K-T-H Fractures/Dislocations in UM CIREN as of 5/5/00

Distribution of Occupant Age by Injured Region



Age Group in Years by Injured Region

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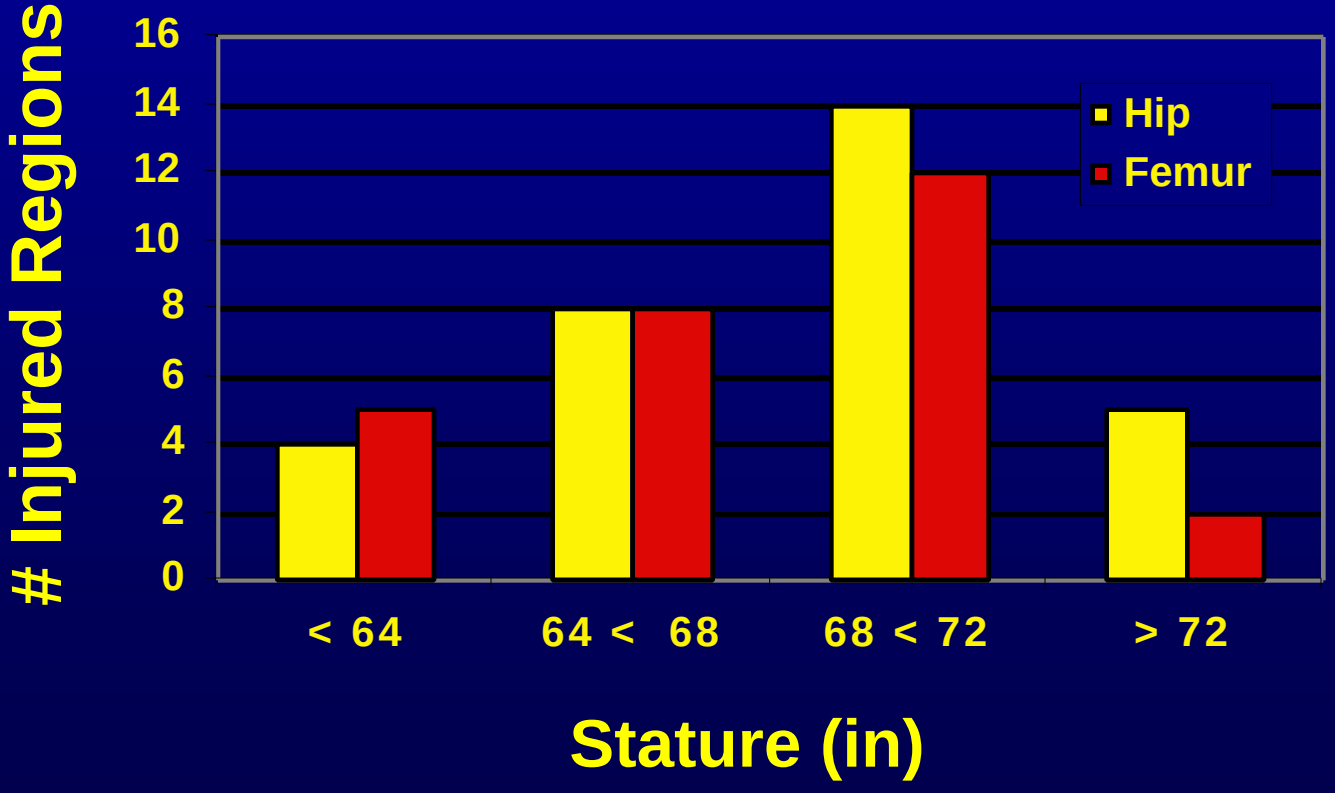
K-T-H Fractures/Dislocations in UM CIREN as of 5/5/00

Distribution of Hip an Femur Fx/Dislocations by Injured Occupant Stature



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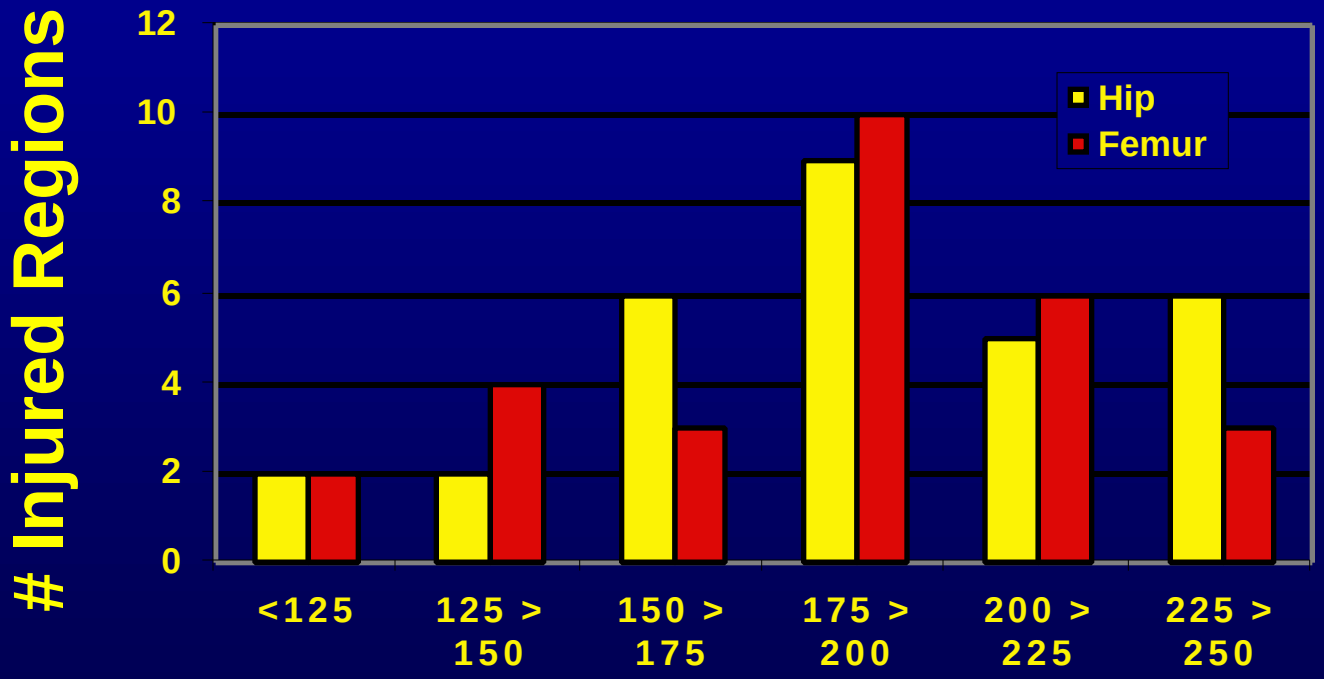
K-T-H Fractures/Dislocations in UM CIREN as of 5/5/00

Distribution of Hip and Femur Fx/Dilocations by Injured Occupant Weight



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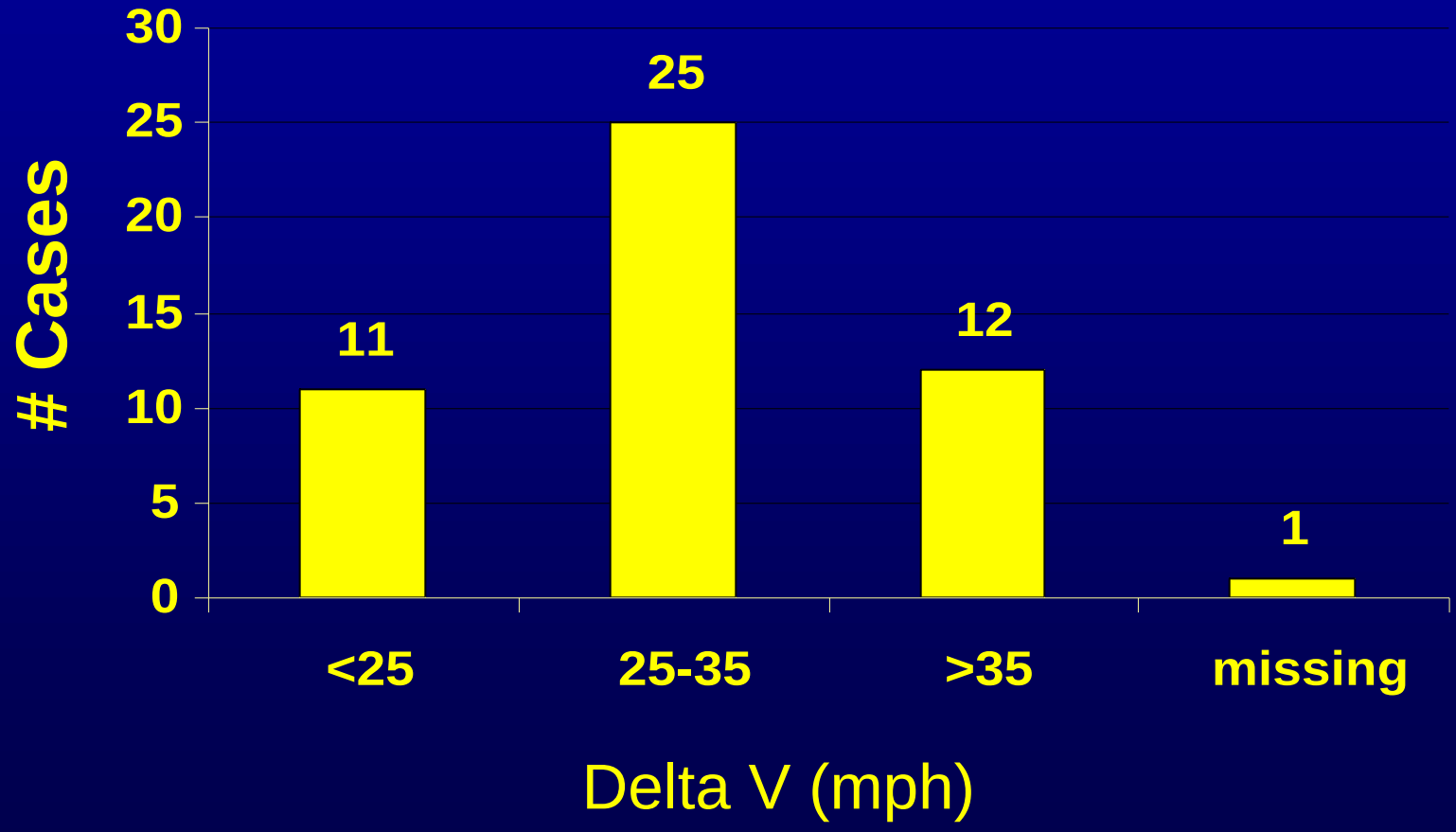
K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Delta V for Injured Occupant Frontal Crashes



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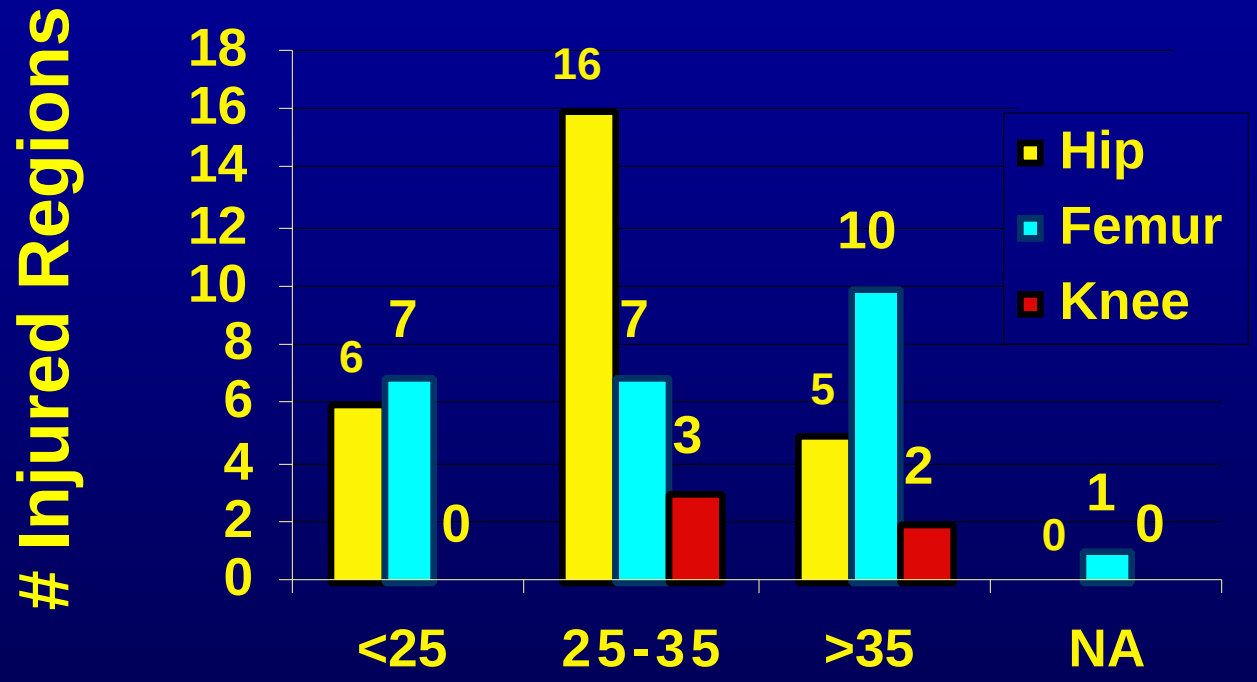
K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

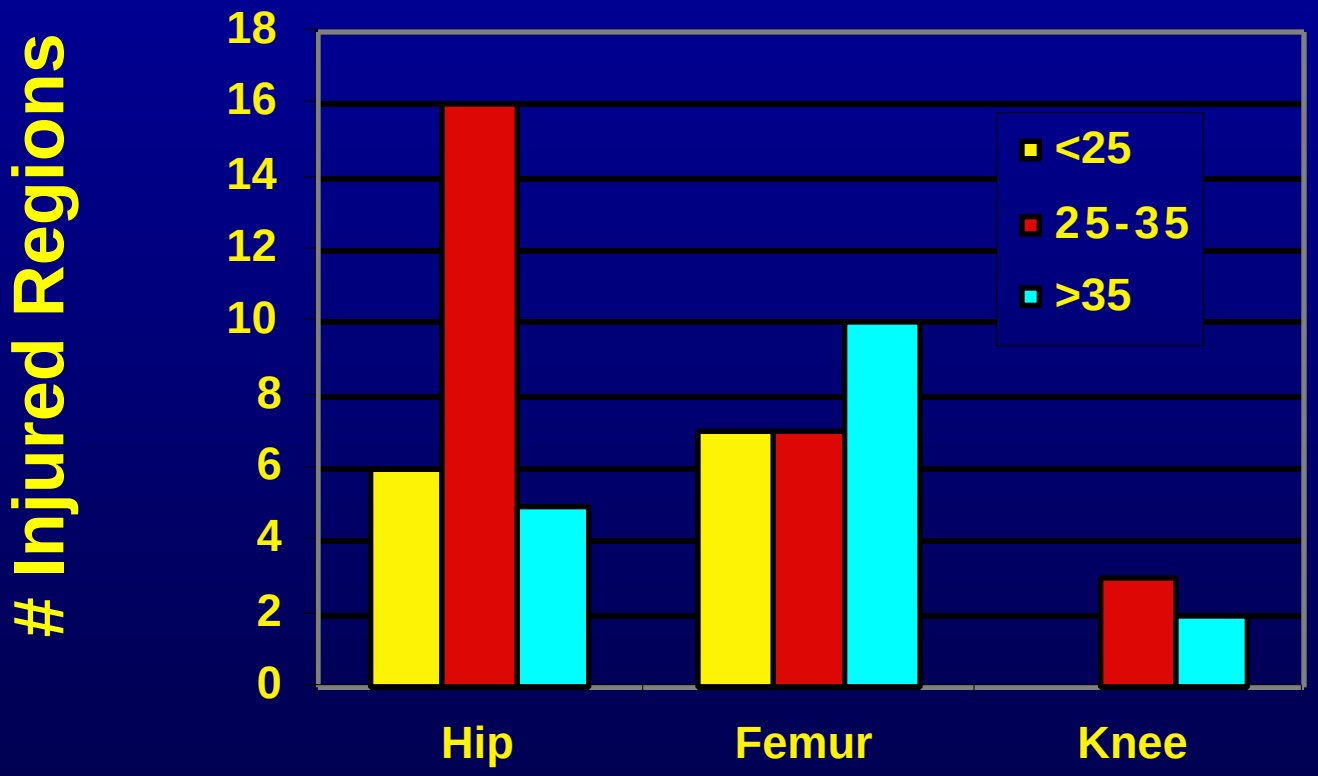
Distribution of Injured Regions by Delta V



Injured Region by Delta V (mph)

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Delta V by Injured Region



K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Injured Occupant Restraint Usage

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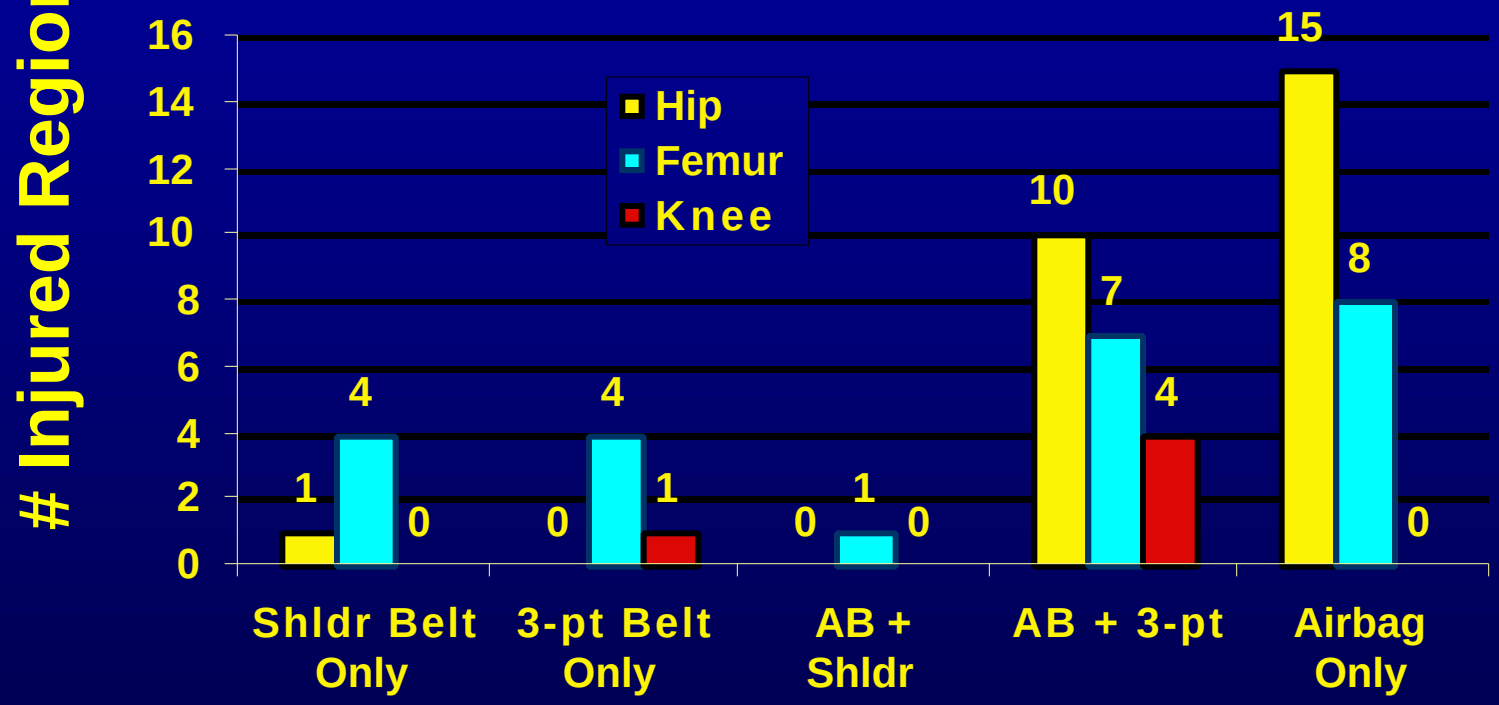
K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Injured Region by Restraint Usage



Injured Region by Injured Occupant Restraint

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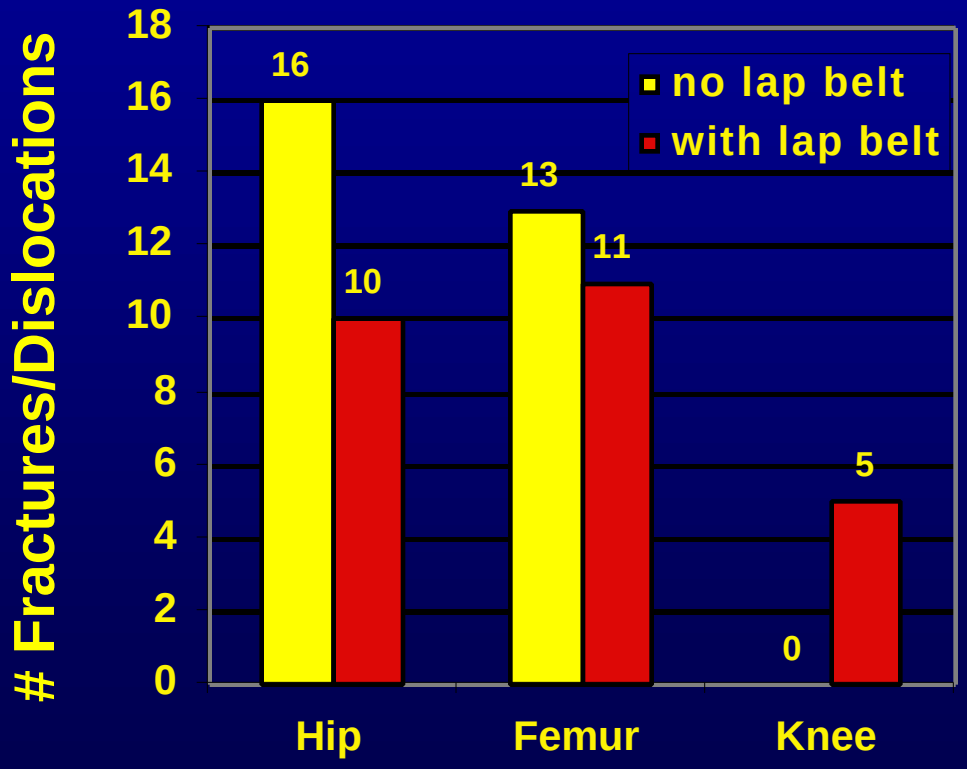
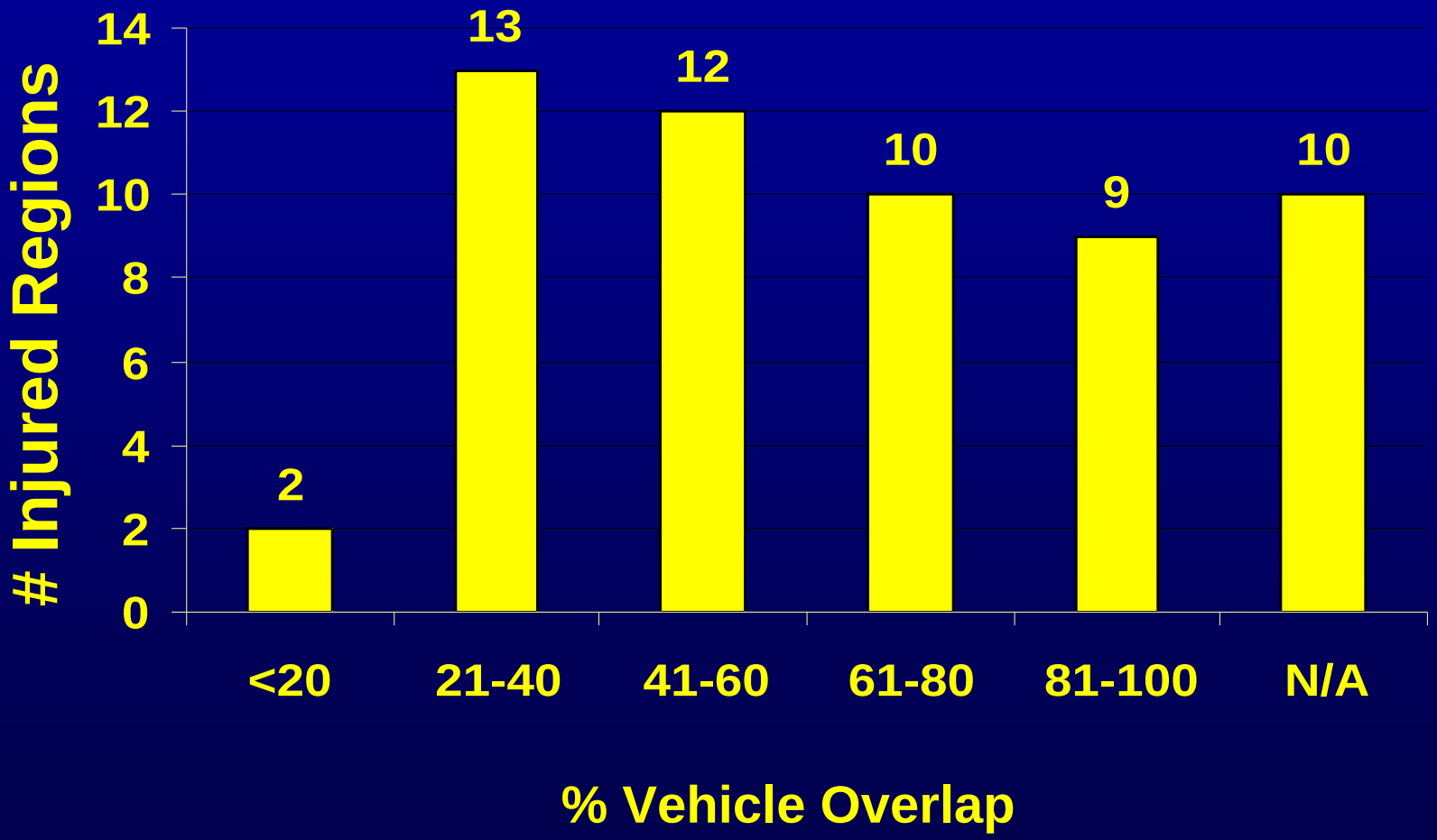
K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Fracture/Dislocations by Lap Belt Usage



K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of % Vehicle Overlap for Injured Occupant Frontal Crashes



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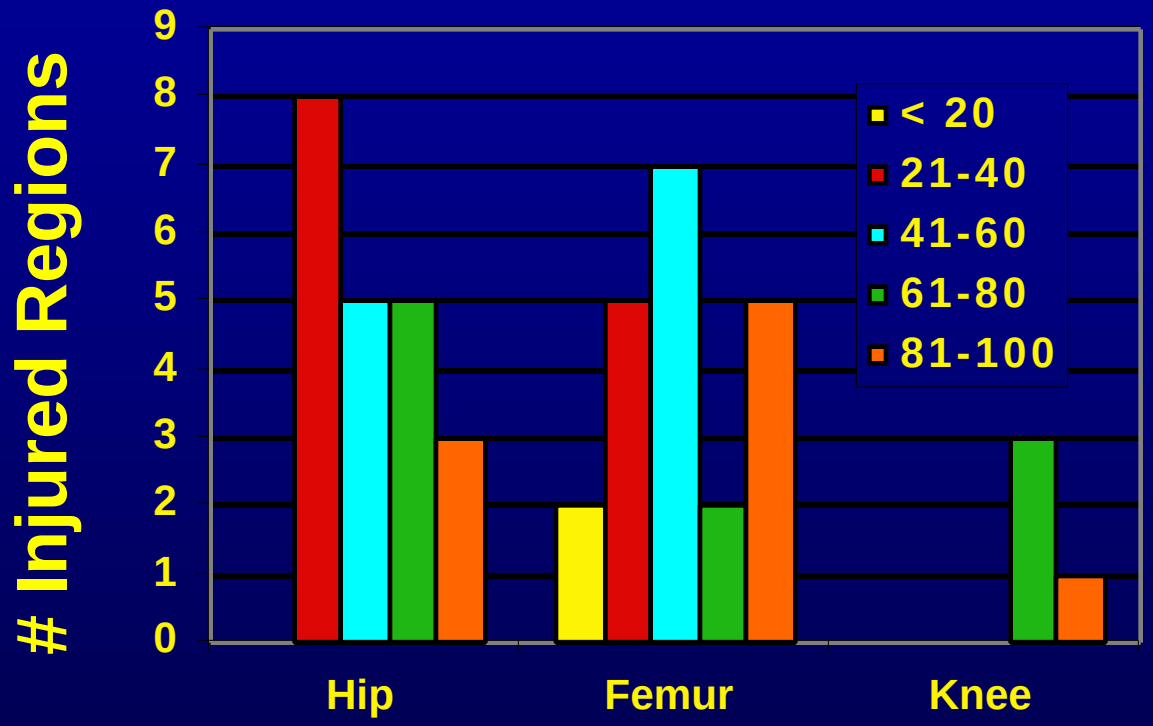
K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

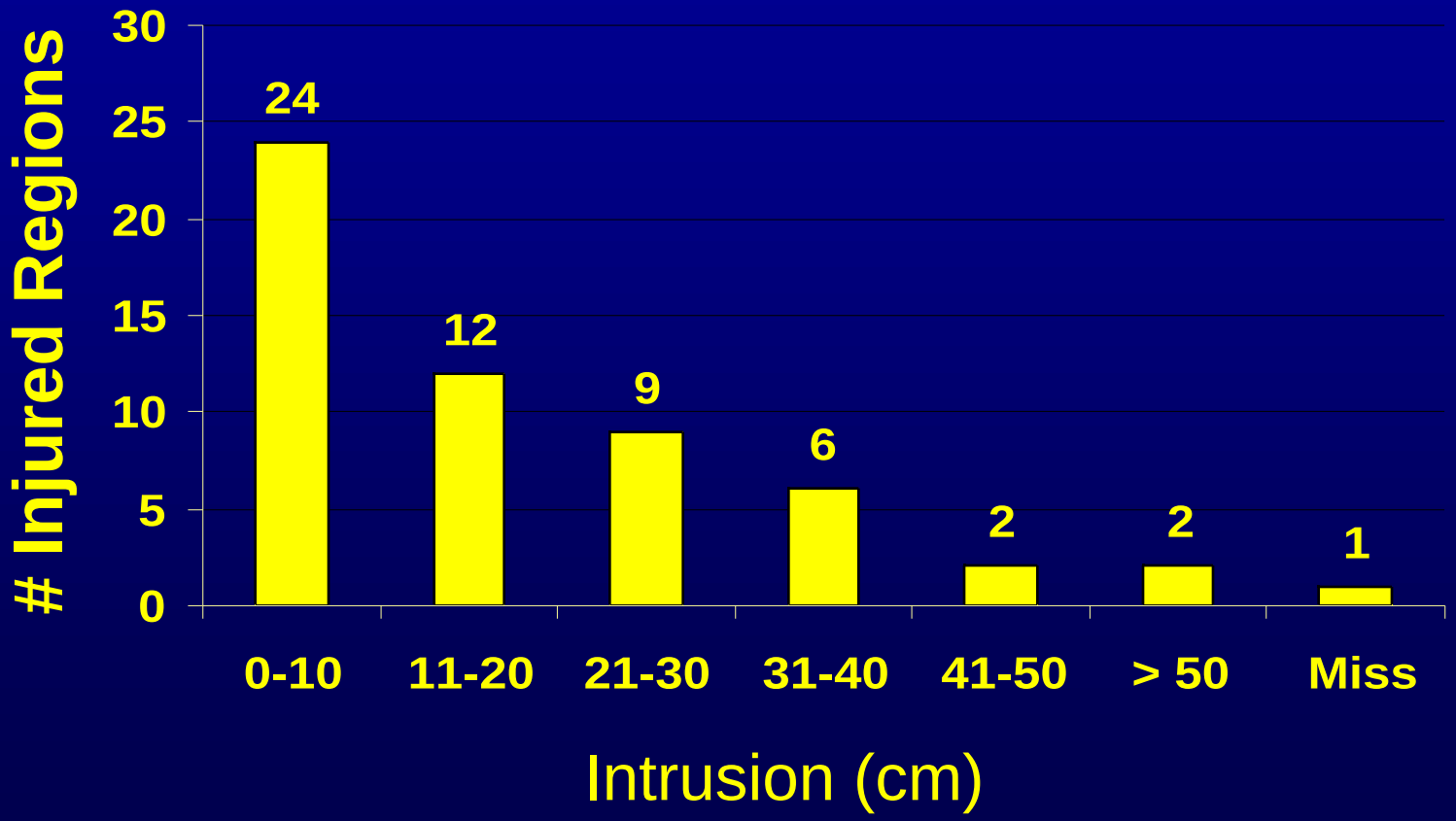
Distribution of %Vehicle Overlap by Injured Region



% VOL by Injured Region

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of IP/Knee-Bolster Rearward Intrusion for Injured Occupant Frontal Crashes



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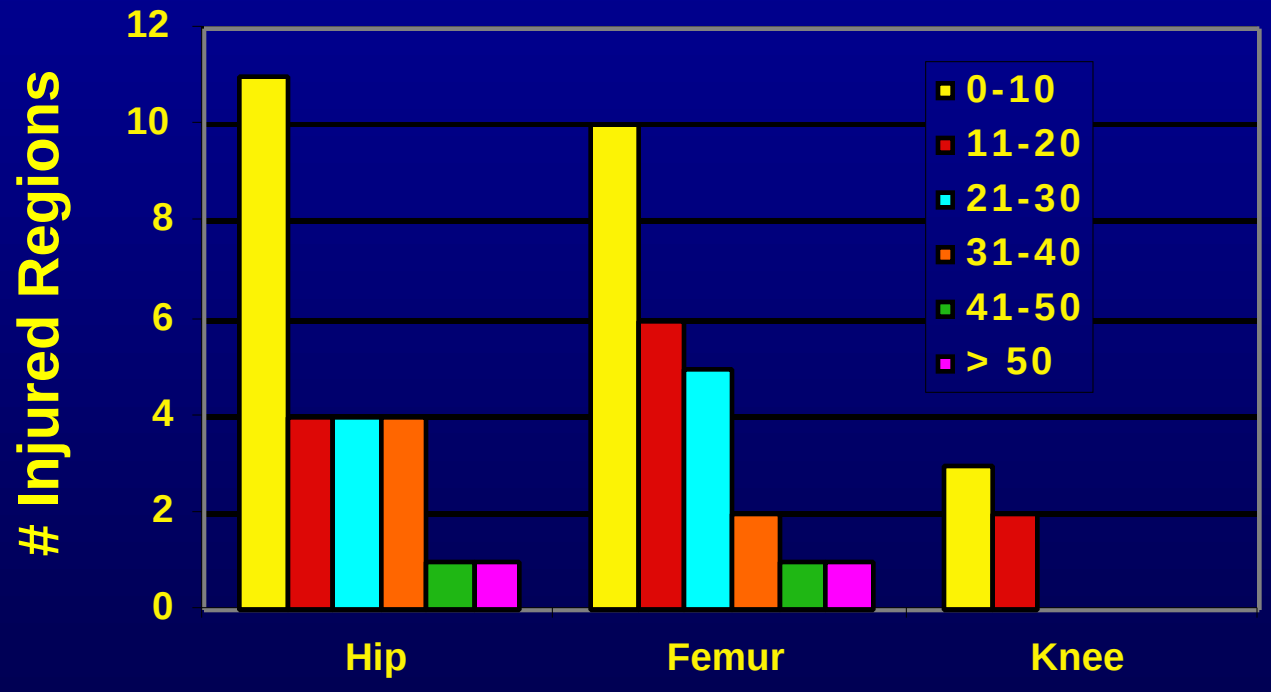
K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution IP/Knee-Bolster Rearward Intrusion by Injured Region



Rearward Intrusion in cm by Injured Region

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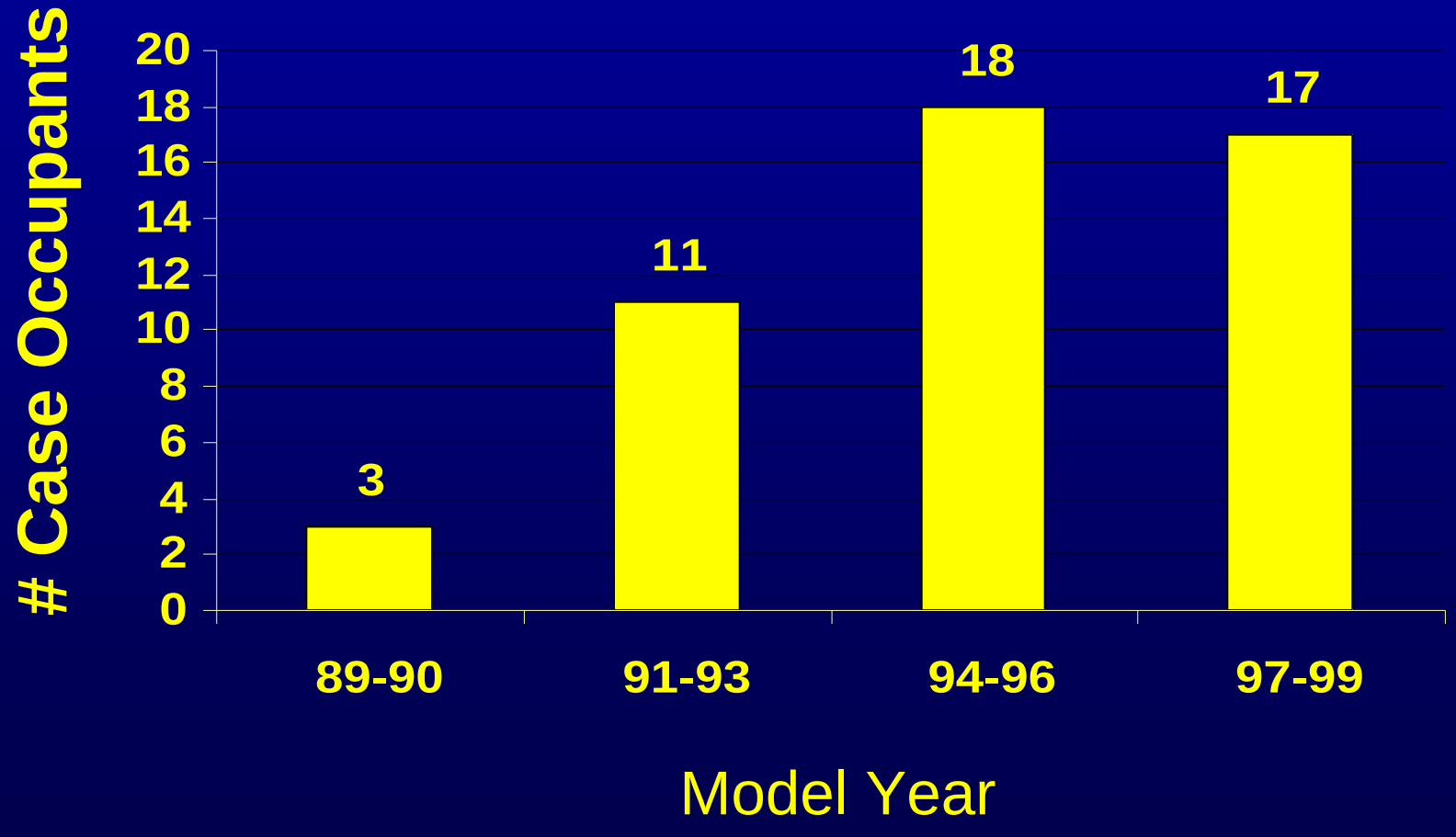
K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Vehicle Model Year for Injured Occupant Frontal Crashes



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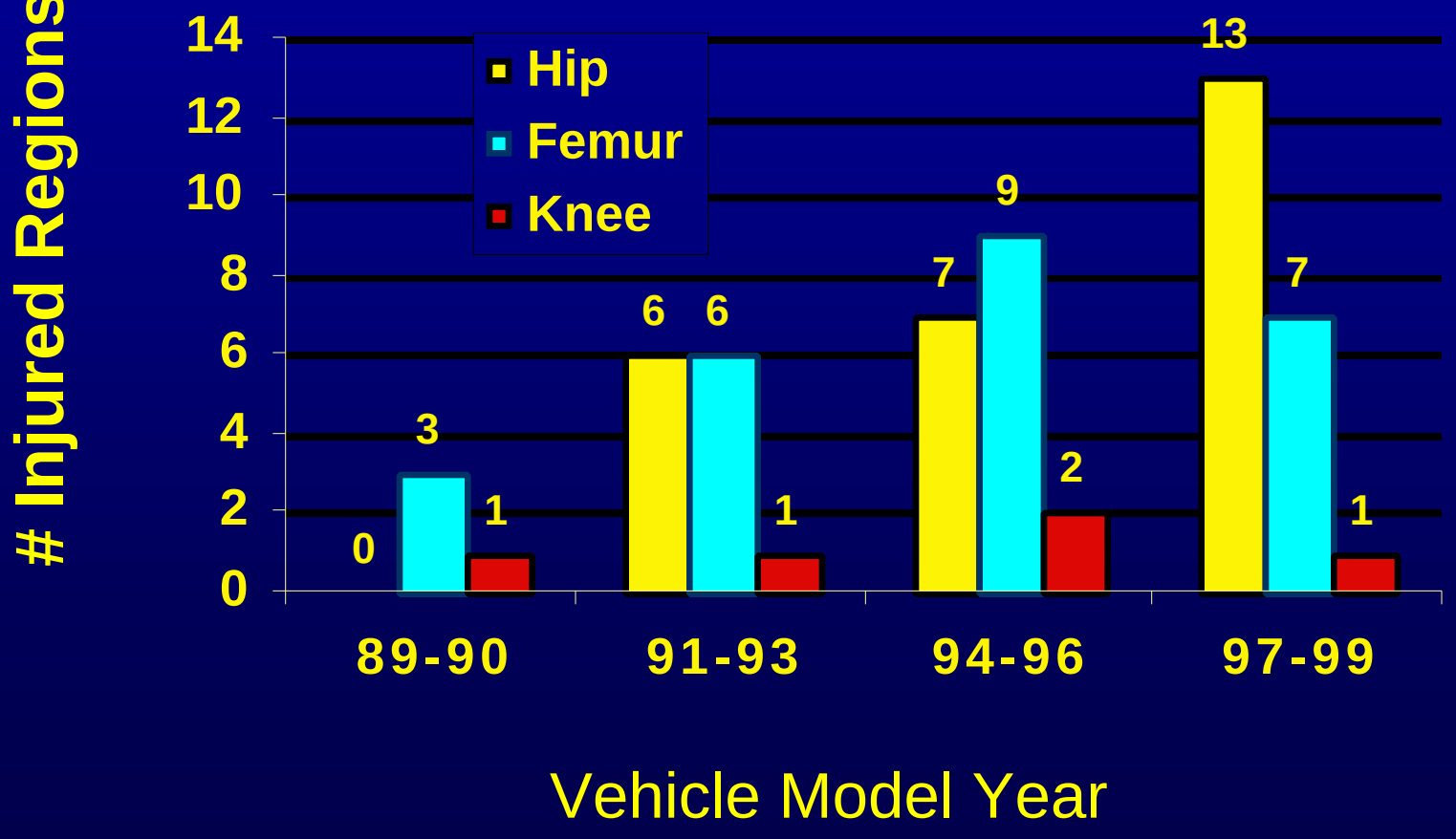
K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Injured Regions by Vehicle Model Year



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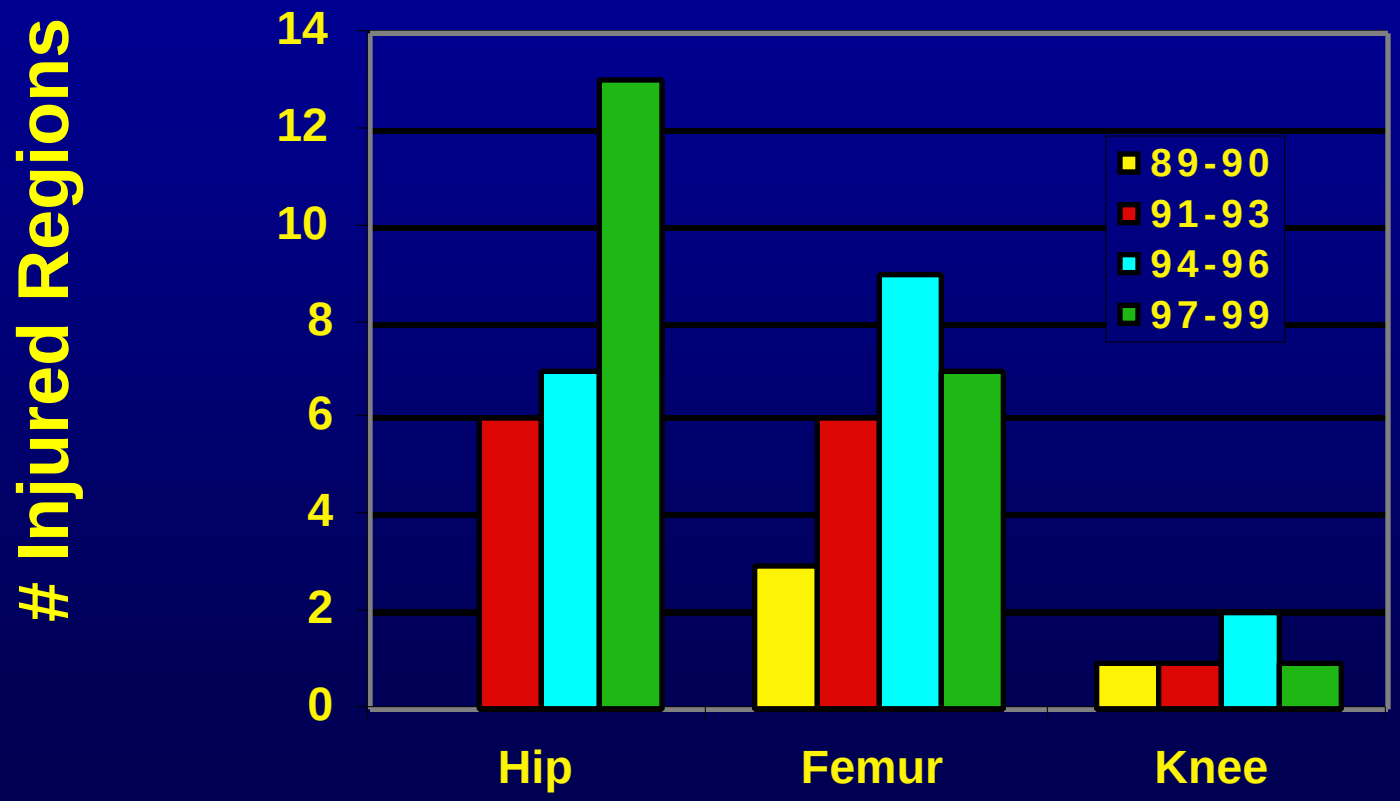
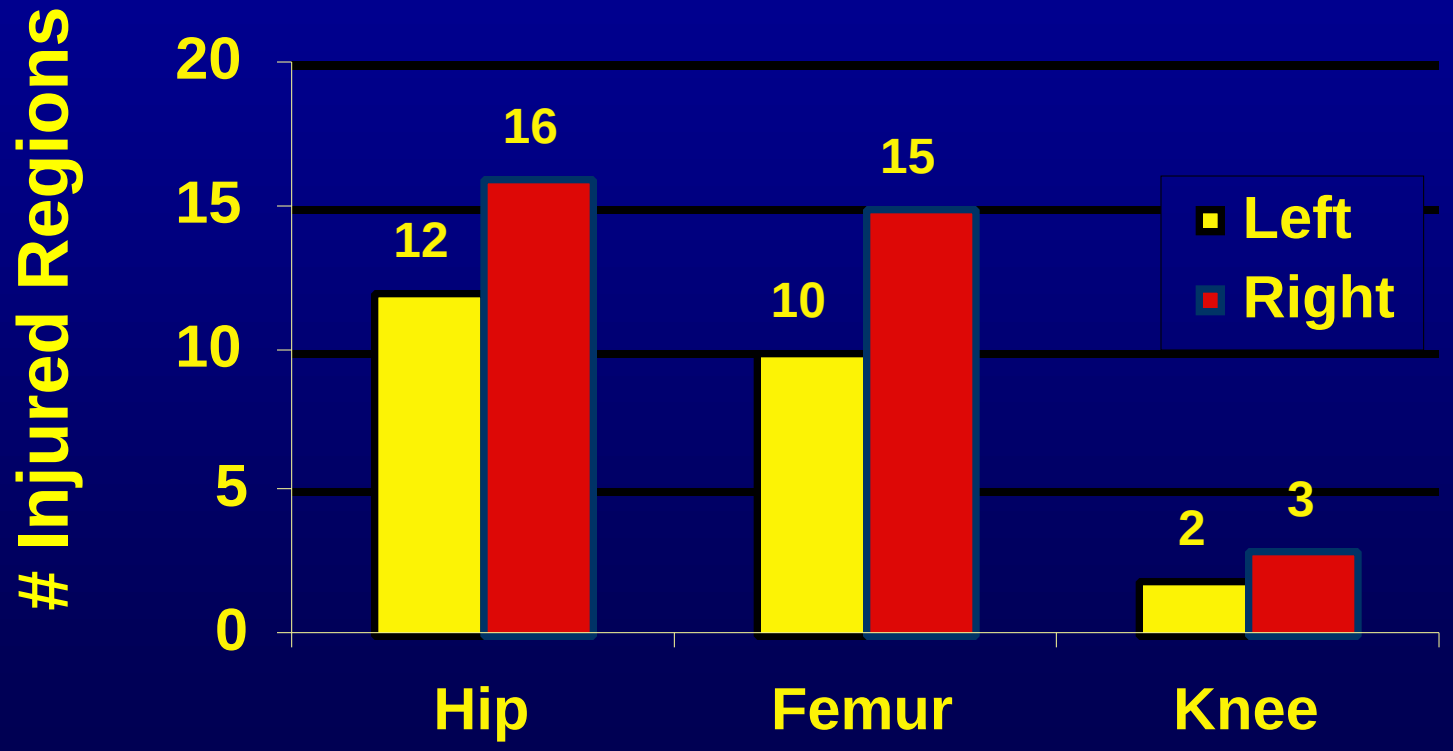
K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Vehicle Model Year by Injured Region



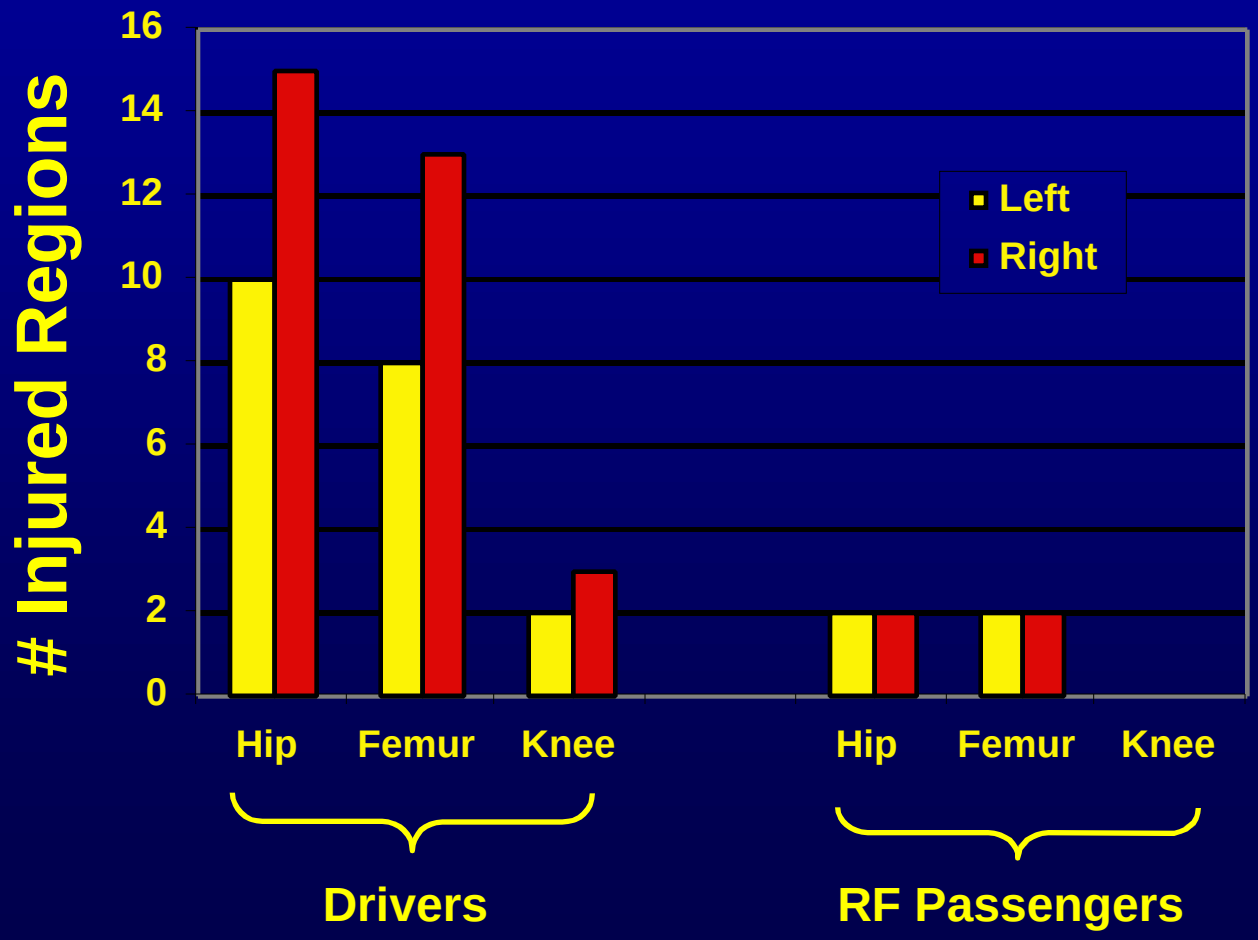
K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Injured Regions by Side of Body



K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Injured Regions by Occupant Location and Side of Body



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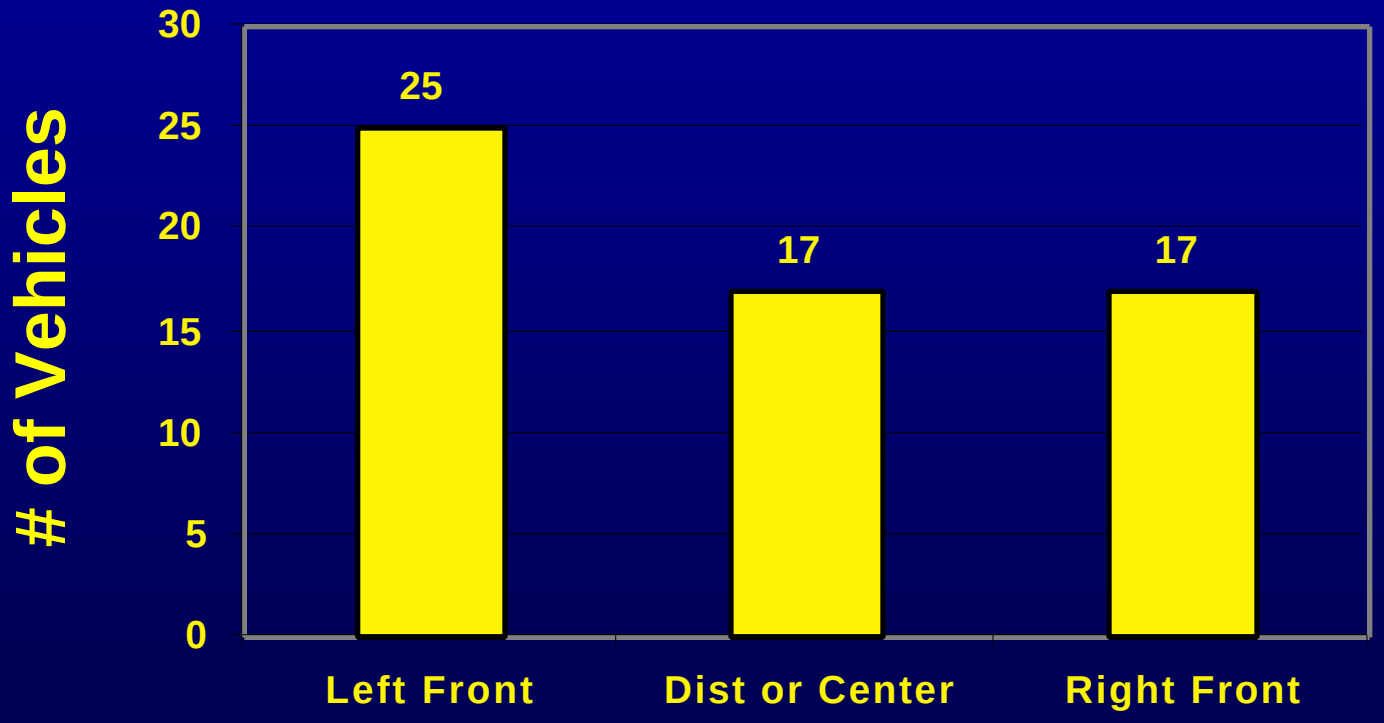
Hip Fractures/Dislocations in UM CIREN Frontal Impacts as of 5/5/00

Distribution of Front-End Damage Location for Frontal Crashes Resulting in Femur or Hip Fx/Disloc.



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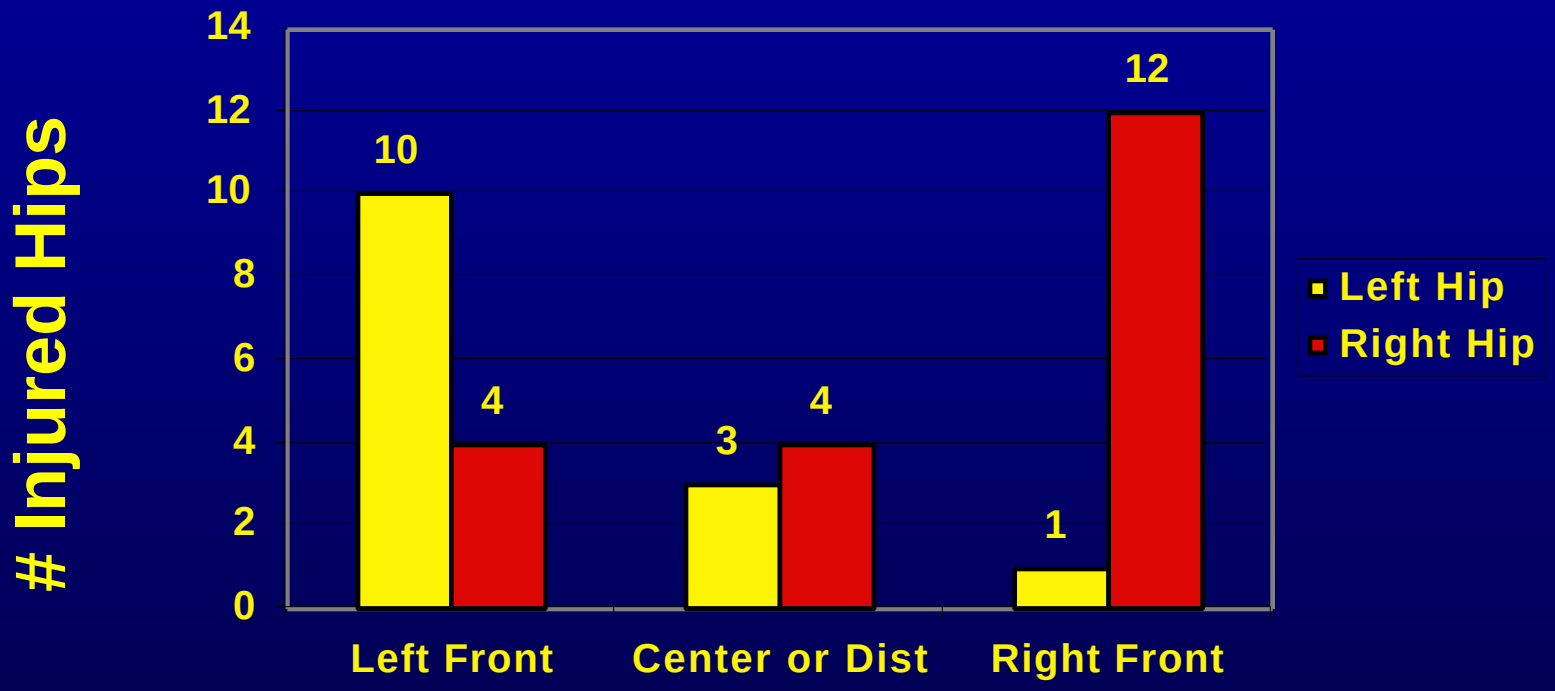
Hip Fractures/Dislocations in UM CIREN Frontal Impacts as of 5/5/00

Side of Hip Fracture/Dislocation by Location of Front-End Damage



Location of Front-End Damage

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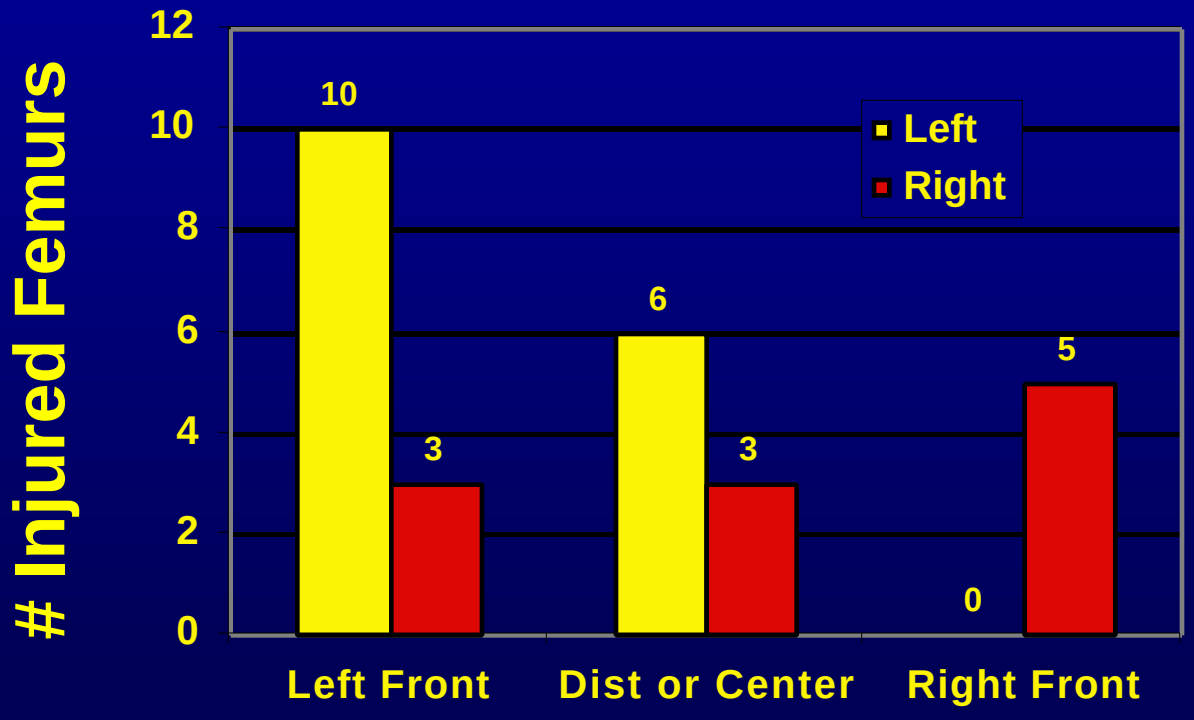
Femur Fractures in UM CIREN Frontal Impacts as of 5/5/00

Side of Femur Fracture by Location of Vehicle Front-End Damage



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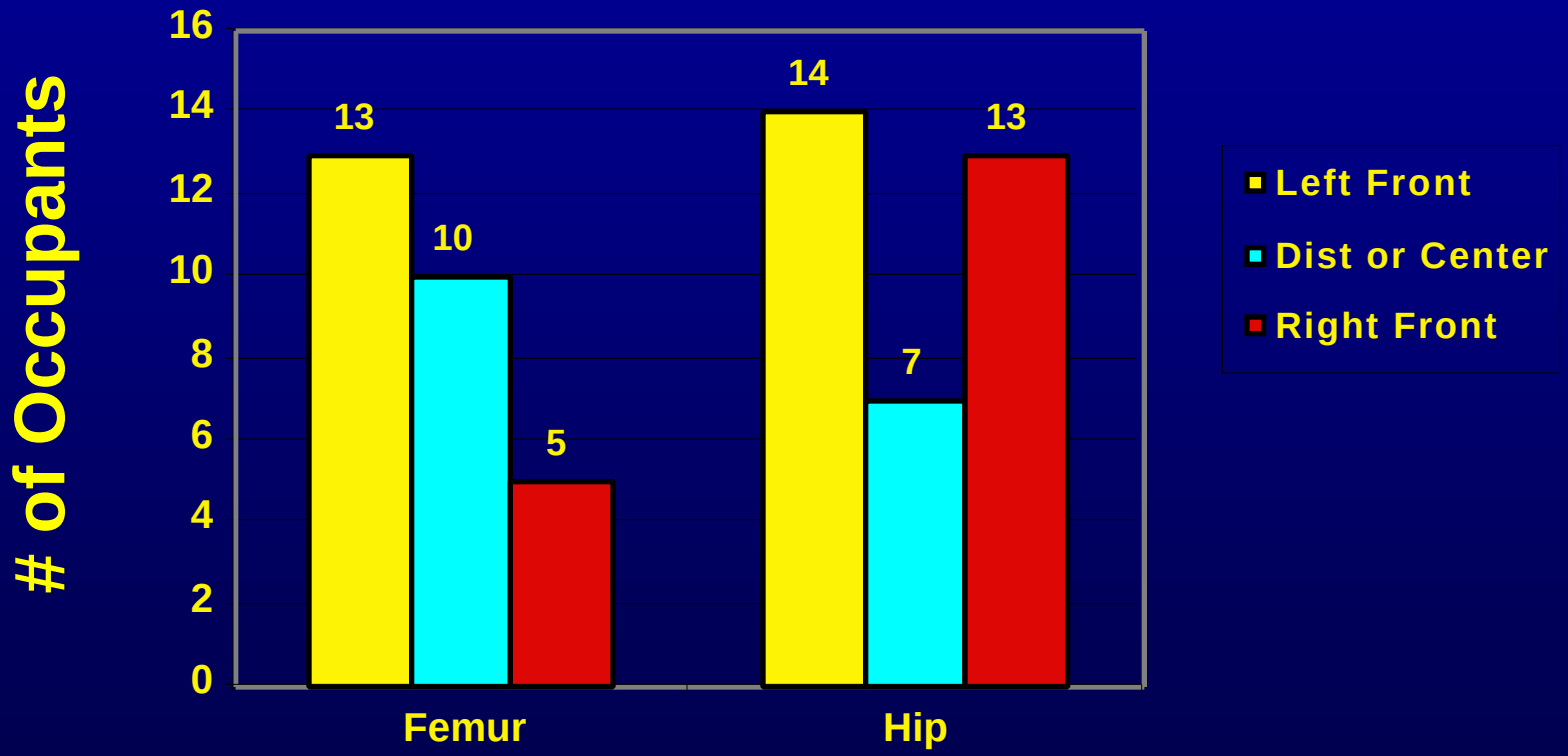
Hip Fractures/Dislocations in UM CIREN Frontal Impacts as of 5/5/00

Distribution of Location of Front-End Damage for Hip and Femur Fxs/Dislocations



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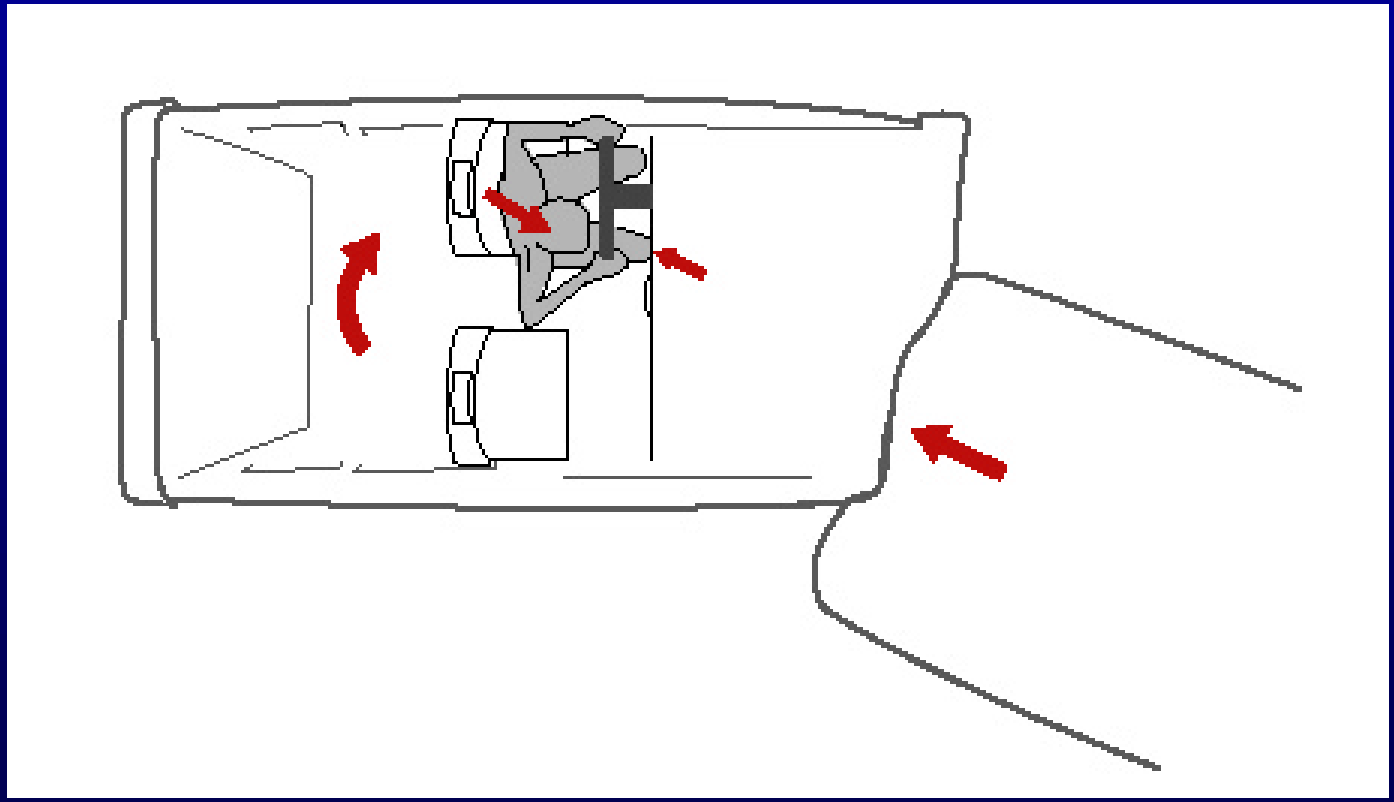
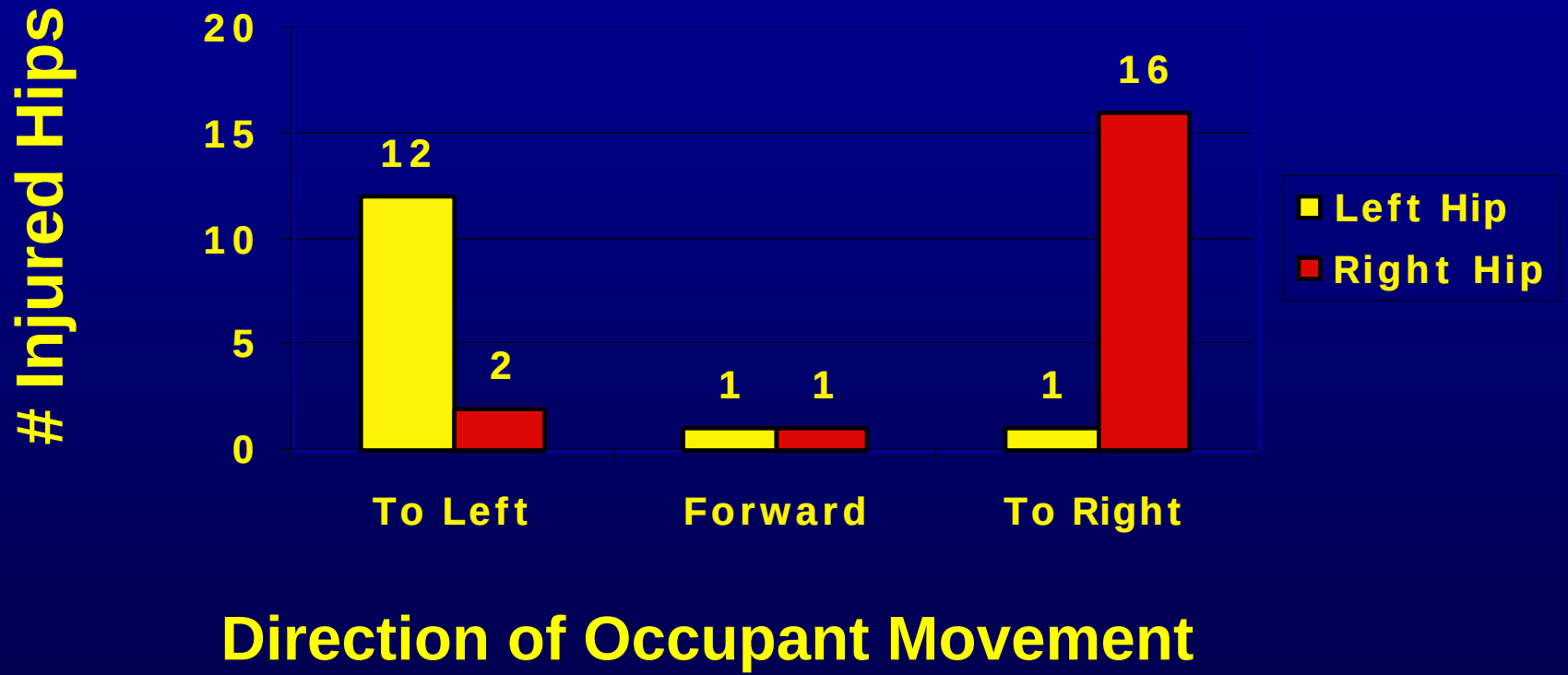
Occupant and Vehicle Kinematics in Frontal Impacts



Hip Fractures/Dislocations in UM CIREN Frontal Impacts as of 5/5/00

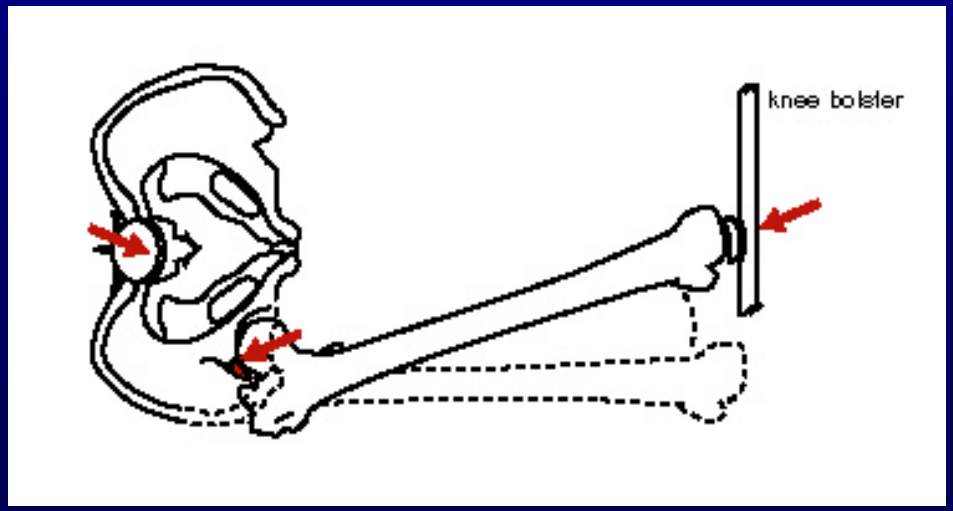
Side of Hip Fracture by Direction of Occupant Movement



Fractures/Dislocations to the Knee-Thigh-Hip Complex

The correspondence of the side of hip fracture to the direction of occupant lateral movement implies two possible contributing factors:

1) hip/thigh adduction



2) asymmetric loading to left and right KTH

Fractures/Dislocations to the Knee-Thigh-Hip Complex
Summary of Observations from UM CIREN Database

- Many case occupant involved in 25 - 40 mph frontal impacts had only AIS 0 to 1 injuries to the head, face, neck, and chest, but sustained serious and disabling injuries to the lower extremities.

Fractures/Dislocations to the Knee-Thigh-Hip Complex
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- Many case occupant involved in 25 - 40 mph frontal impacts had only AIS 0 to 1 injuries to the head, face, neck, and chest, but sustained serious and disabling injuries to the lower extremities.
- There are relatively few serious knee injuries compared to thigh and hip injuries.

Fractures/Dislocations to the Knee-Thigh-Hip Complex
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- There are relatively few serious knee injuries compared to thigh and hip injuries.
- Most hip fractures occurred to the posterior wall/column of the acetabulum, which is consistent with axial loading through the knee and thigh from contact with the knee bolster.

Fractures/Dislocations to the Knee-Thigh-Hip Complex
Summary of Observations from UM CIREN Database

- A large number of femur and hip fracture/dislocations have occurred for crash severities of 25 - 35 mph in the (range of 208 and NCAP testing).

Fractures/Dislocations to the Knee-Thigh-Hip Complex
Summary of Observations from UM CIREN Database

- A large number of femur and hip fracture/dislocations have occurred for crash severities of 25 - 35 mph in the (range of 208 and NCAP testing).
- No clear relationship between femur and hip fractures and rearward knee bolster intrusion is observed.

Fractures/Dislocations to the Knee-Thigh-Hip Complex
Summary of Observations from UM CIREN Database

- There is a nearly uniform distribution of occupant age from 20 to 70 years for occupants with femur and hip fractures & dislocations, although hip fractures appear to be more likely than femur fractures in the elderly.
- Use of a lap belt restraint has limited influence on reducing femur and hip fractures/dislocations.
- There has been a relative increase in the number of hip fractures compared to femur fractures in 1997 - 1999 model years.

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- There has been a relative increase in the number of hip fractures compared to femur fractures in 1997 - 1999 model years.
- **Femur and hip fractures/dislocations seem to be biased toward taller and heavier occupants.**

Fractures/Dislocations to the Knee-Thigh-Hip Complex
Summary of Observations from UM CIREN Database

- Hip Fx/Dislocations tend to occur when the conditions of impact induce lateral as well as forward body movement.

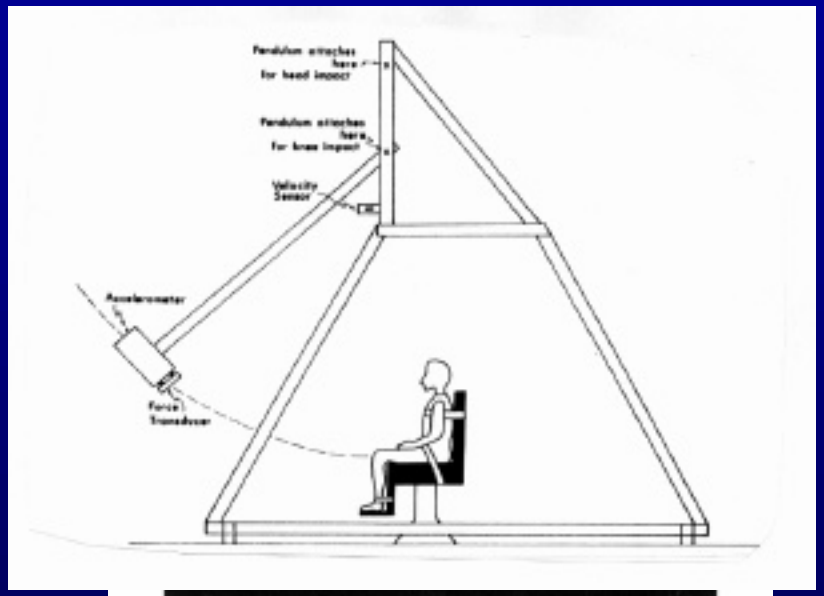
Fractures/Dislocations to the Knee-Thigh-Hip Complex
Summary of Observations from UM CIREN Database

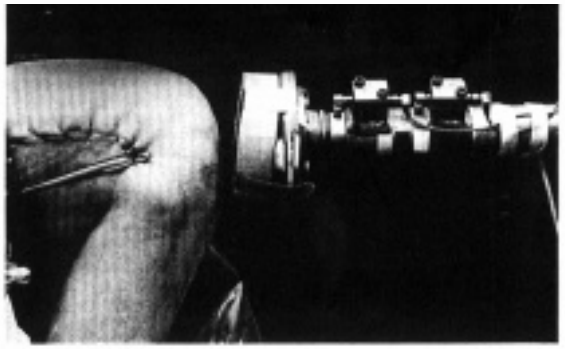
- Hip Fx/Dislocations tend to occur when the conditions of impact induce lateral as well as forward body movement.
- This implies that hip adduction or asymmetric loading of one thigh over the other, or both, are significant contributing factors to the likelihood of hip fracture/dislocations.

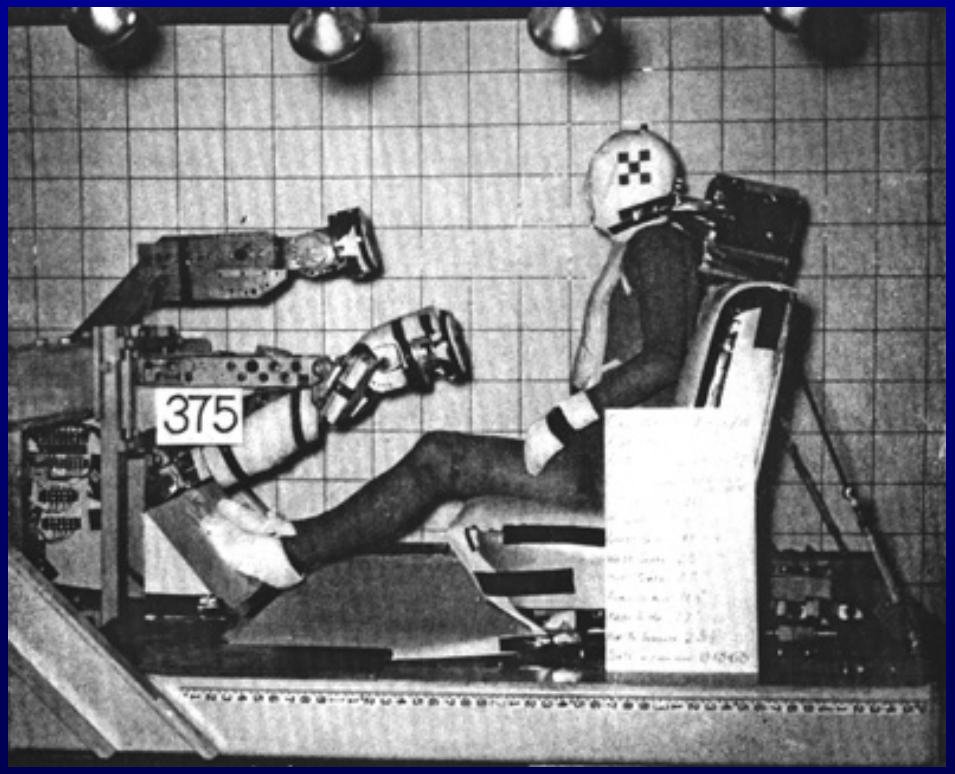
Fractures/Dislocations to the Knee-Thigh-Hip Complex

Biomechanical Studies

Pendulum and Whole Body Testing







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Fractures/Dislocations to the Knee-Thigh-Hip Complex

Biomechanical Studies

(1965 - 1987)

- L. Patrick et al. 9th Stapp Conference, 1965
- F. Cooke and D. Nagel, 13th Stapp Conference, 1969
- K. Kilfert and G. voight, 15th Stapp Conference, 1972
- J. King et al., 17th Stapp Conference, 1973
- W. Powell et al., 18th& 19th Stapp Conference, 1974 & 1975
- J. Melvin et al., 19th Stapp Conference, 1975
- C. Kroell et al., 20th Stapp Conference, 1976
- D. Viano, 21st Stapp Conference, 1977
- G. Nusholtz et al., 26th Stapp Conference, 1982
- F. Brun-Cassan et al., 7th IRCOBI, 1982
- B. Donnelly and D. Roberts, 31st Stapp Conference, 1987

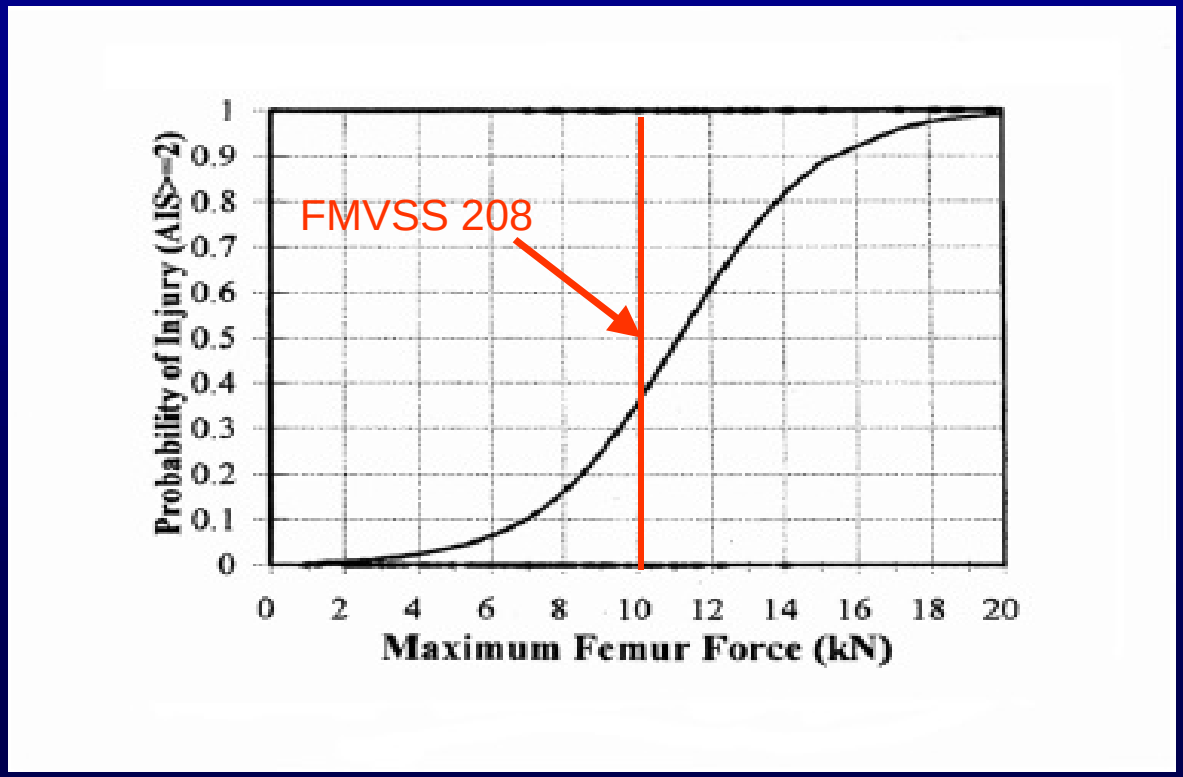
Fractures/Dislocations to the Knee-Thigh-Hip Complex

Biomechanical Studies

- Most studies have dealt with knee and femur fractures.
- Mechanisms of, and tolerance to, hip fractures/dislocations in frontal impact loading are not well understood.
- Causes for femur fracture versus hip-joint fractures and dislocations have not been determined.

Fractures/Dislocations to the Knee-Thigh-Hip Complex
FMVSS 208 K-T-H Injury Criteria vs Injury Risk Curve

- The current FMVSS 208 KTH injury criteria of 10 kN (2250 lb) is based on femur tolerance, not hip tolerance.



Fractures/Dislocations of the Knee-Thigh-Hip Complex

Relevant Questions

- Are the KTH injury criteria of FMVSS 208 appropriate?
- Are energy-absorbing knee bolsters protecting the knees at the expense of the hip or femur?

Fractures/Dislocations of the Knee-Thigh-Hip Complex

Hypothesis

A better understanding of:

1) **the factors involved in hip fractures/dislocations versus femur fractures, and**
2) **hip injury tolerance to frontal impact loading through the knee,**

will lead to improved knee bolster, seat, and restraint designs that will reduce the likelihood of hip fractures/dislocations.

Fractures/Dislocations of the Knee-Thigh-Hip Complex

Next Steps

- Examine KTH fracture/dislocation frontal-impact database based on cases from several CIREN centers.
- Study frontal-impact hip fracture/dislocation tolerance and injury factors in the laboratory through a NHTSA Cooperative agreement with U of M.